PROCEEDINGS

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No. 1—*April*, 1938.

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Third Annual General Meeting.

The Third Annual General Meeting of the National Institute of Sciences of India was held at 3 P.M. on Saturday the 8th January, 1938, in the Senate House, Calcutta University

The following Fellows were present —

Prof M N Saha, *President* (in the chair)
Rai Bahadur Dr S L Hora, *Honorary Treasurer*
Prof S. P Agharkar, *Honorary Secretary*

Dr Nazir Ahmad
Prof S L Ajrekar
Prof P R Awati
Prof K N Bahl
Prof A C Banerji
Prof S K Banerji
Prof Y Bharadwaja
Mr T. P Bhaskara Shastri
Dr B L Bhatia
Dr S N Chakravarti
Mr G Chatterjee
Dr H Chaudhuri
Dr. B N. Chopra
Prof S Datta
Prof H B Dunnicliff
Sir Lewis Fermor
Dr Gilbert Fowler
Prof S L Ghose
Prof J Ghosh
Prof. P N Ghosh
Dr. B S Guha
Khan Bahadur M Afzal Husain
Dr S Krishna
Dr M S Krishnan
Prof P Neogi
Prof G R Paranjpe
Dr R P Paranjpye
Dr B N Prasad
Dr B Prashad
Dr K R Ramanathan
Dr L A Ramdas
Rao Bahadur G N Rangaswami Ayyangar
Mr B Rama Rao
Dr H Srinivasa Rao
Prof P R Ray
Dr H K Sen
Principal J M Sen
Lt-Col R B Seymour Sewell
Prof M R Siddiqi
Dr E Spencer
Prof. V Subrahmanyan
Rao Bahadur T S Venkataraman
Rao Bahadur B Venkatesachar
Mr D N Wadia

The meeting was also attended by about 88 visitors

1. The minutes of the Seventh Ordinary General Meeting were read and confirmed.

2 The President appointed Dr B N Prasad and Mr D N Wadia to act as scrutineers of the ballot papers received for the election of officers and other members of the Council for the year 1938.

3. Prof S L Ajrekar, Prof S L Ghose, Dr R P Paranjpye and Prof B Venkatesachar signed the duplicate obligation form as per Rule 13

4. The following Ordinary Fellows were admitted as Fellows as per Rule 13.

Prof. Y Bharadwaja
Dr. B L Bhatia.
Mr. G. Chatterjee.
Prof. G R. Paranjpe.
Dr H S. Rao
Lt-Col. R B Seymour Sewell
Prof. M. R. Siddiqi

5 The Secretary announced that since the last Ordinary General Meeting the Institute had lost one Ordinary Fellow by death (Sir J C. Bose) and four by resignation (Mr. E A Wraight, Sir Gerald Trevor, Sir Martin Forster, and Dr T. Royds)

6 The President appointed Dr B. N. Prasad and Dr B S Guha to act as scrutineers of the voting papers received in connection with the modification to Rule 7(*b*) On the votes received and the votes of those who voted at the meeting, the proposed alteration in the rule was rejected

7. The Annual Report prepared by the Council was adopted (see pp 3-21).

8 The following were declared to have been elected officers and other members of the Council for the year 1938

President.	Prof M N Saha	*Treasurer*	Dr B S Guha
Vice Presidents	Prof S S Bhatnagar,	*Foreign Secretary*	Prof B Sahni
	Brevet-Col R N Chopra	*Secretaries*	Prof S P Agharkar,
			Dr A M Heron

Members of Council Mr T P Bhaskara Shastri, Dr G S Bose, Mr H G Champion, Prof J C Ghosh, Dr F H Gravely, Khan Bahadur M Afzal Husain, Prof K S Krishnan, Dr R B Lal, Prof S K Mitra, Prof J N Mukherjee, Dr C W B Normand, Sir Arthur Olver, Dr Baini Prashad, Prof N R Sen, Lt Col S S Sokhey, Prof V. Subrahmanyan, Col J Taylor, Rao Bahadur B Venkatesachar

9 The President delivered his address, the subject being 'The Problem of Indian Rivers' (see pp 23–47) The address forms an introduction to the Symposium on River Physics, organized under the joint auspices of the National Institute of Sciences of India, the Indian Science Congress Association and the Indian Physical Society, and was held on Sunday the 9th January, 1938, in the same hall at 1-30 P M

The Proceedings of the Symposium are being published separately

ANNUAL REPORT

The Council of the National Institute of Sciences of India have pleasure in submitting the following report on the general concerns of the Institute for the year 1937, as required by the provisions of rule 18(*f*)

Membership.

The number of Fellows on the roll of the Institute at the beginning of the year was 144 Ordinary Fellows and 11 Honorary Fellows Ten Ordinary Fellows and four Honorary Fellows were elected during the year in accordance with the procedure laid down in the Regulations The Institute lost two Ordinary Fellows and two Honorary Fellows by death and one Ordinary Fellow by resignation The total number of Fellows on the roll at the end of the year is 151 Ordinary and 13 Honorary Fellows

Office accommodation

The need for more accommodation for the offices of the Institute, that was stressed in last year's report, is an ever-present problem Difficulty is already being experienced in finding storage room for the stock of the Institute's publications that is rapidly accumulating Accommodation is needed for the growing library of the Institute and a reading room for Fellows when they visit the rooms of the Institute Increased accommodation is also required for the additional staff, appointment of which will have to be considered by the Council at an early date

The Council are considering the question of approaching the Government of India for accommodation in one of their buildings

Meetings

The second Annual Meeting was held at the Osmania University, Hyderabad, on the 5th January, 1937. An account of the meeting was published in the *Proceedings*, Vol III, pp 1-2

Three Ordinary General Meetings were held during the year, the first on the 25th March, 1937 in the Physics Lecture Theatre of the Allahabad University, the second on the 27th and 28th August, 1937 in the All-India Institute of Hygiene and Public Health, Calcutta, and the third on the 6th November, 1937 at the University of Delhi Accounts of these meetings will be found in the *Proceedings*, Vol III, pp 387-388, 411-412 and 413-414 The papers read at the first of these meetings, with a few exceptions, have

been published in the *Proceedings*, Vol III, No. 3. Those read at subsequent meetings will be published in due course.

At the meeting on the 27th and 28th August, 1937, a Symposium on the 'Malaria Problem in India' was held, which was attended by a large number of medical and scientific workers from all parts of India

The Council.

The officers and members of Council for the year 1937 were elected at the second Annual General Meeting held on the 5th January, 1937. Together with the representatives of the co-operating Academies and the Indian Science Congress Association the Council was constituted as follows :—

President	Prof M N Saha
Vice Presidents	Prof S S Bhatnagar Brevet Col R N Chopra
Additional Vice Presidents	Sir U N Brahmachari Prof N R Dhar Rao Bahadur T S Venkataraman Dr T S Wheeler
Treasurer	Rai Bahadur Dr S L Hora
Foreign Secretary	Prof B Sahni
Secretaries	Prof S P Agharkar. Dr A M Heron
Members of Council	Mr T P Bhaskara Shastri Dr G S Bose Sir Bryce Burt Prof J C Ghosh Dr F H Gravely. Khan Bahadur M Afzal Husain Prof K S Krishnan. Dr. R. B. Lal. Prof S K Mitra Prof J N Mukherjee Dr C W. B Normand Dr Baini Prashad Prof. N R Sen Lt.-Col S S Sokhey Col. J Taylor Sir Gerald Trevor Rao Bahadur B. Venkatesachar Mr F. Ware Brigadier Sir Harold Couchman } *Ex-officio* Sir Lewis Fermor } *Ex-officio*
Additional Members of Council	Mr C C Calder Prof P S. MacMahon. Prof G Matthai Mr W. D West

The Council held 9 ordinary and 1 special meeting during the year. The special meeting was held on the 7th June, 1937 to consider the terms on which the Government of India sanctioned a grant of Rs 6,000 per annum to the Institute.

During the absence of Prof. S. P. Agharkar out of Calcutta for a month in May-June, 1937 the President nominated Dr. Baini Prashad, as per Rule 47, to act as Honorary Secretary.

The Council appointed Dr C. S. Fox, Mr. E. R. Gee, Mr. D. N. Wadia and Prof. B. Sahni as its delegates to the 17th International Geological Congress held at Moscow in July. Only Dr Fox was able to attend. Dr E. Spencer also attended the 17th International Geological Congress.

Sectional Committees.

There were no changes in the personnel of the Sectional Committees during the year, except that Sir U. N. Brahmachari was appointed to act as Secretary of the Physiology Committee during the absence out of India of Brevet-Col. R. N. Chopra.

Additional Committees.

A Committee consisting of Prof. M. N. Saha, Prof. J. N. Mukherjee, Mr. W. D. West, Dr A. M. Heron and Prof. S. P. Agharkar was appointed to consider Prof. V. Subrahmanyan's letter regarding the mode of election of the Council of the Institute and to suggest suitable alterations to Rule 48, for consideration of the Council.

Publications.

Four numbers of the *Proceedings* and three numbers of the *Transactions* and the second number of *Indian Science Abstracts* for the year 1935 have been published since the last Annual Report. Copies of all these have been circulated to Fellows.

The Council resolved to supply the publications of the Institute free to Universities and similar bodies making annual grants to the funds of the Institute. It was also resolved to fix the annual subscription for the publications of the National Institute as follows :—

Transactions, (separately per part),
Proceedings, Rs 10 per annum,
Indian Science Abstracts, Rs 25 per volume,

and the combined subscription for all the publications of the Institute at Rs.40 per annum.

In order to make the publications of the Institute more widely known, the Council decided to extend the exchange distribution list. In this connection the Secretaries of Sectional Committees have been asked to prepare distribution lists in regard to their respective sciences. These lists have been referred to the Publication Committee for their views.

Exchanges.

Ten additional Societies and Institutions have been placed on the exchange list for the Institute's publications during the year, bringing the total number on the list to eighty (*vide* Appendix IV).

Library.

Three hundred and seventy books and parts of periodicals were added to the library during the year (*vide* Appendix V) The Royal Botanical Gardens, Edinburgh, who were placed on the exchange list during the current year, very kindly sent a complete set of their publications (*Proceedings and Transactions* and *Notes*) for the last twelve years

Presents and Donations

The following grants-in-aid have been sanctioned during the year to the Institute :—

(1) Rs.300 per annum for two years from the Government of H E H the Nizam.

(2) Rs 6,000 per annum from the Government of India commencing with the financial year 1937-38 (The grant for the year will be received during the year 1938-39)

Finance

An audited statement of accounts of the National Institute for the period from 1st December, 1936 to 30th November, 1937 is submitted (*vide* Appendix VI) The total ordinary receipts for this period are Rs.9,294-1-6, inclusive of grants-in-aid amounting to Rs 1,300-0-0, and the ordinary payments Rs 13,392-12-0, showing an excess of payments over receipts of Rs 4,098-10-6. A sum of Rs 224-0-0 was realized on account of Admission Fees and a similar amount was funded in terms of Rule 71.

At the beginning of the year the cash position of the Institute was as follows :—

		Rs	A	P
In Savings Bank account		5,014	8	0
,, Government paper		33,000	0	0
,, Current account		1,643	8	5
,, hand		15	2	6
	TOTAL	39,673	2	11

At the end of the year, however, the cash position of the Institute was as follows :—

		Rs.	A	P.
In Savings Bank account		2,089	9	0
,, Government paper		33,000	0	0
,, Current account		700	15	5
,, hand		8	0	0
	TOTAL	35,798	8	5

Rules and Regulations

The following alteration in the wording of Section 8 of Regulation 4 regarding Sectional Committees was adopted by the Council —

> 'A Physiology Committee for Animal Physiology, Pathology, Bacteriology, Psychology and other medical and veterinary subjects' in place of 'A Physiology Committee for Animal Physiology and Medical subjects'.

APPENDICES

I List of Fellows.
II Abstracts of Proceedings of the Council
III Committees, 1938
IV List of Institutions on the exchange list
V Periodicals received for the library
VI Audited statement of accounts, Dec. 1936 Nov 1937.
VII Budget Estimate, Dec 1937–Nov 1938

APPENDIX I.

LIST OF FELLOWS.

ORDINARY FELLOWS.

1. ABRAHAM, LT -COL W E V, A R C S (I.), F G S, M Inst P T, Senior Geologist, Burmah Oil Co, Ltd, Burma, Khodaung, Magwe, Burma (1936)
2. AGHARKAR, S. P, M A, Ph D, F L.S., Ghose Professor of Botany, Calcutta University, 35 Ballyganj Circular Road, Calcutta
3. AHMAD, NAZIR, M Sc, Ph D, Director, Indian Central Cotton Committee's Technological Laboratory, Matunga, Bombay
4. AJREKAR, S L, B A, I E S, Professor of Botany, Gujerat College, Ahmedabad
5. ANANDARAO, K, Rao Bahadur, M A, I E S, Professor of Mathematics, Presidency College, Madras
6. ASH, W C, B Sc, M Inst C E, A M I Mech E, Bengal Club, Calcutta.
7. AWATI, P R, B A, D I C, I E S, Professor of Zoology, Royal Institute of Science, Mayo Road, Bombay 1
8. BAGCHEE, K D, D Sc., D I C, Mycologist, Imperial Forest Research Institute, Dehra Dun, U.P
9. BAHL, K N, D.Sc, D Phil, Professor of Zoology, Lucknow University, Lucknow
10. BANERJI, A. C, M.Sc., M A, F R A S, I E S, Professor of Mathematics, Allahabad University, Allahabad
11. BANERJI, S K, D Sc, Meteorologist, Meteorological Office, Poona 5
12. BEESON, C F C., D Sc, Forest Entomologist, Imperial Institute of Forest Research, Dehra Dun, U P.
13. BHARADWAJA, Y, M.Sc, Ph D (Lond), F L S, Professor of Botany and Head of the Department, Hindu University, Benares. (1937).
14. BHASKARA SHASTRI, T. P, M A, F R A S, Director, Nizamia Observatory, Hyderabad (Deccan)
15. BHATIA, B L, D Sc, F Z S, F R M S, F A Sc, Director, The Science Press of India, 13 Hotusingh Road, Lahore. (1937)
16. BHATNAGAR, S. S, O B E, D Sc, University Professor of Chemistry and Director, University Chemical Laboratories, Lahore
17. BHATTACHARYA, D R, M Sc, Ph D, Dr ès Sciences (Paris), Professor of Zoology, Allahabad University, 7 Malaviya Road, Allahabad
18. BOMFORD, MAJOR GUY, R E., Survey of India, Dehra Dun (1935)
19. BOSE, D M, M A, B Sc, Ph D, Palit Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta
20. BOSE, G S., D Sc, M B, Head of the Department of Experimental Psychology, Calcutta University, 92 Upper Circular Road, Calcutta
21. BOSE, S. N, M Sc, Professor of Physics, Dacca University, Dacca
22. BOSE, S. R, M A, Ph D., F R S E, Professor of Botany, Carmichael Medical College, Calcutta. (1935)
23. BRAHMACHARI, SIR U. N, Kt, Rai Bahadur, M A, M D, Ph.D, F R A S B, K I.H., Physician, Medical College Hospitals, Calcutta (Retired), 82-3 Cornwallis Street, Calcutta.
24. BURNS, W., D Sc, I A.S, Offg Agricultural Expert, Imperial Council of Agricultural Research, New Delhi (1935)
25. BURRIDGE, W., D M, M.A (Oxon), Professor of Physiology, Lucknow University, Lucknow.
26. BURT, SIR B. C., Kt, C I E, M B E, B Sc, I A S., Offg Vice-Chairman, Imperial Council of Agricultural Research, New Delhi.

27 CALDER, C C, B Sc (Agr.), F.L.S, Formerly Director, Botanical Survey of India and Superintendent, Royal Botanic Gardens, Sibpur, Howrah C/o Messrs Thomas Cook & Sons, Bankers, Berkeley Street, London

28. CHAKRAVARTI, S N, M Sc., D Phil, F C.S, Chemical Examiner to the Government of U P and C P, Agra (1935)

29 CHAMPION, H G, M A, Conservator of Forests, Western Circle, Naini Tal, United Provinces

30 CHATTERJEE, G, M.Sc., Meteorologist-in Charge, Upper Air Observatory, Agra (1935)

31 CHAUDHURI, H, M Sc, D Sc, Ph D, D I C, Reader and Head of University Teaching in Botany and Director, Kashyap Research Laboratory, Punjab University, Lahore

32 CHOPRA, B N, D Sc, F L S, Assistant Superintendent, Zoological Survey of India, Indian Museum, Calcutta (1935)

33 CHOPRA, BREVET-COL R N, C I E, M D, Sc D, F R A S B, K H P, I M S, Director, School of Tropical Medicine, Calcutta

34 CHOWLA, S, M A, Ph D., Professor of Mathematics, Government College, Lahore

35 COUCHMAN, BRIGADIER SIR HAROLD, Kt, D S O, M C, Formerly Surveyor General of India C/o Lloyds Bank Ltd, R Dept, 6 Pall Mall, London, S W 1

36 COULSON, A L, D Sc, D I C, F G S, Superintending Geologist, Geological Survey of India, Indian Museum, Calcutta (1935)

37. DASTUR, R H, M Sc, Cotton Physiologist, Agricultural College, Lyallpur, Punjab

38 DATTA, S, M Sc, D Sc, D I C, Professor of Physics, Presidency College, Calcutta (1935)

39 DEY, B B, D Sc, F.I C., I E S, Professor of Chemistry, Presidency College, Madras

40. DHAR, N. R, D Sc, F I C, I E S, University Professor of Chemistry, Allahabad University, Allahabad

41 DUNN, J A, D Sc, D I C, F G S, Geologist Geological Survey of India, Indian Museum, Calcutta (1935)

42 DUNNICLIFF, H B, M A, Sc D, F I C, I E S, University Professor of Inorganic Chemistry, Government College, Lahore

43 DUTT, S B, D Sc, Reader in Organic Chemistry, Allahabad University, Allahabad (1935)

44 EVANS, P, B A, F G S, Geologist, The Burmah Oil Company, Ltd, P O Digboi, Assam

45 FERMOR, SIR LEWIS L, Kt, O B E, D Sc, A R S M, M Inst M M, F G S, F R A S B, F R.S., Formerly Director, Geological Survey of India. C/o Lloyds Bank, 6 Pall Mall, London, S W 1

46 FORSTER, SIR MARTIN O, Kt, D Sc, Ph D, F R S, Old Banni Mantap, Mysore City

47 FOWLER, GILBERT J, D Sc, F L C, Consulting Chemist, Mackay's Gardens Annexe, Grames Road, Cathedral P O, Madras

48 FOX, C S, D Sc, M I Min E, Superintending Geologist, Geological Survey of India, Calcutta.

49 GEE, E. R, M A, F G S, Geologist, Geological Survey of India, Indian Museum, Calcutta (1935).

50. GHOSE, S L., M Sc, Ph D., Professor of Botany, Government College, Lahore

51 GHOSH, J, M A, Ph D, Professor of Mathematics, Presidency College, Calcutta (1936)

52 GHOSH, J C, D Sc, Professor and Head of the Department of Chemistry, Dacca University, Dacca

53. GHOSH, P N, M A, Ph D, Sc D (Hon), F.Inst P, Ghose Professor of Applied Physics, Calcutta University, 92 Upper Circular Road, Calcutta

54 GLENNIE, LT COL E A, D.S O, R E, Survey of India, Dehra Dun

55. GRAVELY, F. H., D.Sc, F.R.A.S.B., Superintendent, Government Museum, Museum House, Egmore, Madras

56 GUHA, B. S, M.A., Ph D, Assistant Superintendent, Zoological Survey of India, Indian Museum, Calcutta

57. GUHA, P. C, D Sc, Acting Professor of Organic Chemistry, Indian Institute of Science, Hebbal, Bangalore. (1935)
58. HADDOW, J R, B Sc, M R C V S, D V S M, Veterinary Research Officer-in-charge of Serology, Imperial Veterinary Research Institute, Muktesar-Kumaun, U P
59. HERON, A M, D Sc, F G S, F R G S, F R S E, F R A S B, Director, Geological Survey of India, Indian Museum, Calcutta
60 HORA, S L, Rai Bahadur, D Sc, F R S E, F L S, F Z S, F R A S B, Asst Superintendent, Zoological Survey of India, Indian Museum, Calcutta
61 HUSAIN, M AFZAL, Khan Bahadur, M A, M Sc, I A S, Principal, Punjab Agricultural College, Lyallpur, Punjab
62 IYENGAR, M O P, M A, Ph D, F L S, University Professor of Botany, Madras University, Triplicane, Madras
63 KAPUR, S N, Ph D, Imperial Forest Research Institute, Dehra Dun
64 KICHLU, P K, D Sc, Professor of Physics, Government College, Lahore (1935)
65 KOSHY, P K, F R C P, Professor of Anatomy, Medical College, Madras
66 KOTHARI, D S, M Sc, Ph D, Reader and Head of the Physics Department, Delhi University (1936)
67. KRISHNA, S, Ph D, D Sc, F I C, Forest Biochemist, Imperial Forest Research Institute, Dehra Dun (U P)
68 KRISHNAN, K S, D Sc, Mahendra Lal Sircar Professor of Physics, Indian Association for the Cultivation of Science, 210 Bow Bazar Street, Calcutta
69 KRISHNAN, K V, M B B S, L R C P, D B, D Sc, Bacteriological Research Officer, School of Tropical Medicine, Calcutta
70 KRISHNAN, M S, A R C S, Ph D, D I C, Geologist, Geological Survey of India, Indian Museum, Calcutta (1935)
71 LAL, R B, M B B S, D P H, D T M & H, D.B, Offg. Director, All India Institute of Hygiene & Public Health, Calcutta (1935)
72. LAW, S C, M A, B L, Ph D, M B O U, 50 Kailas Bose Street, Calcutta (1936)
73 MACMAHON, P S, M Sc, B Sc, (Oxon), F I C, I E S, Professor of Chemistry, Lucknow University, Lucknow
74 MAHAJANI, G S, M A, Ph D, M L.C, Principal and Professor of Mathematics, Fergusson College, Poona 4
75. MAHALANOBIS, P C, M A, B Sc, I E S, Professor of Physics, Presidency College, Calcutta
76 MAHESWARI, P, D Sc, Lecturer in Botany, Allahabad University, Allahabad (1935)
77. MATTHAI, GEORGE, M A, Sc D, F L S, F Z S, F R S E, Professor of Zoology, Government College, Lahore
78 MEHRA, H. R, M Sc, Ph D, Reader in Zoology, Allahabad University, Allahabad
79 MEHTA, K C, Rai Bahadur, M Sc, Ph D, Professor of Botany, Agra College, Agra
80 MILLS, J P, M A, I C S, Secretary to H E the Governor, Stonylands, Shillong, Assam. (1936).
81 MITRA, S. K, D Sc, Ghose Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta
82. MITTER, P C., M A, Ph.D, Palit Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta
83 MOHAMMAD, WALI, M A, Ph D, I E S, University Professor of Physics, Lucknow University, Lucknow
84 MOWDAWALLA, F. N, M A, M I E E, Mem A.I E E, M I E, 301 Frere Road, Fort, Bombay
85 MUKHERJEE, J N, D Sc, F C S, Ghose Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta
86 NAIK, K. G, D Sc, F I C., Professor of Chemistry, Baroda College, Baroda
87 NARAYAN, A L, M A, D Sc, F I.P, Director, Solar Physics Observatory, Kodaikanal.
88. NEOGI, P, M A, Ph D, I.E.S., Senior Professor of Chemistry, Presidency College, Calcutta (1936).
89 NORMAND, C W B, M A, D Sc, Director-General of Observatories, Meteorological Office, Poona 5,

90 OLVER, COL SIR ARTHUR, C B, C M G, F R C V S, Animal Husbandry Expert, Imperial Council of Agricultural Research New Delhi

91 PARANJPE, G R, M Sc, A I I Sc, I E S, Professor of Physics, Royal Institute of Science, Bombay (1937)

92 PARANJPYE, R P, D Sc, Vice Chancellor, Lucknow University, Lucknow

93 PARIJA, P K, M A, B Sc, I E S, Professor of Botany, Ravenshaw College, Cuttack

94 PARKINSON, C E, Deputy Conservator of Forests, Minbu Division, Minbu, Burma (1936)

95 PERCIVAL, F G, Ph D, F G S, Superintendent of Mines and Quarries, Tata Iron & Steel Co, Ltd, 3 Beldih Lake Road, Jamshedpur (1936)

96 PHILPOT, H P, B Sc (Eng), A M Inst C E, M I Mech E, M I A E, M I M, Principal and Jodhpur Hardinge Professor of Technology, Engineering College, Benares Hindu University, Benares

97 PINFOLD, E S, M A, F G S, Geologist, The Attock Oil Co, Ld, Rawalpindi

98 PRASAD, B N, M Sc, D Sc, Ph D, Mathematics Department, Allahabad University, Allahabad (1936)

99 PRASAD, MATA, D Sc F I C, Professor of Inorganic and Physical Chemistry, Royal Institute of Science, Bombay (1935)

100 PRASHAD, BAINI, D Sc, F R S E, F L S, F Z S, F R A S B, Director, Zoological Survey of India, Indian Museum, Calcutta

101 PRUTHI, H S, M Sc, Ph D, Imperial Entomologist, Imperial Agricultural Research Institute, New Delhi

102 QURESHI, MUZAFARUDDIN, Ph D, Professor of Chemistry, Osmania University, Hyderabad (Deccan)

103 RAI, B SUNDARA, Dewan Bahadur, M A, Ph D, Director of Fisheries, Madras (1935)

104 RAMANATHAN, K R, M A, D Sc, Meteorologist, Colaba Observatory, Bombay

105 RAMDAS, L A, M A, Ph D, Agricultural Meteorologist, Poona (1935)

106 RANGASWAMI AYYANGAR, G N, Rao Bahadur B A, I A S, Millets Specialist, Agricultural Research Institute, P O Lawley Road, Coimbatore, S I

107 RAO, B RAMA, M A, D I C, F G S, Director, Geological Survey Department, Mysore State, Bangalore

108 RAO, C V HANUMANTHA, M A, Professor of Mathematics, Punjab University Lahore

109 RAO, H SRINIVASA, M A, D Sc, Assistant Superintendent, Zoological Survey of India, Indian Museum, Calcutta (1937)

110 RAO, K RANGADHARMA, D Sc (Madras and London) Reader in Physics, Andhra University, Waltair (1937)

111 RAY, B B, D Sc, Khaira Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta (1935)

112 RAY, J N, D Sc, Ph D, F I C, Professor of Organic Chemistry, University Chemical Laboratories, Lahore (1935)

113 RAY, SIR P C, Kt, M A, Ph D, D Sc, F R A S B, Emeritus Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta

114 RAY, P R, M A, Khaira Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta

115 ROW, LT COL R, M D, D Sc, I M S (Hon), 27 New Marine Lines, Bombay 1

116 ROY, S C, Rai Bahadur, M A, B L, Editor, 'Man in India', Ranchi

117 ROYDS, T, D Sc, Formerly Director, Solar Physics Observatory, Kodaikanal; 27 Rutland Road, South Port, Lancs, England

118 SAHA, M N, D Sc, F R S, F R A S B, University Professor of Physics, Allahabad University, Allahabad

119 SAHNI, B, M A., Sc D, D Sc, F G S, F R S, F R A S B, University Professor of Botany, Lucknow University, Lucknow

120 SARKAR, P B, Dr ès Sc, A I C, Lecturer in Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta (1935)

121 SEN, B M, M A, M Sc, I E S, Principal, Presidency College, Calcutta.

122. SEN, H. K., M A, D Sc, D I C., Director, Indian Lac Research Institute, Namkum, Ranchi.

123. SEN, J. M., B Sc, M Ed (Leeds), Dip Ed (Oxford), T D (London), F.R.G S, Principal, Krishnagar College, Krishnagar (1935)

124. SEN, N R, D Sc, Ph D, Ghose Professor of Applied Mathematics, Calcutta University, 92 Upper Circular Road, Calcutta

125 SENGUPTA, N N, Ph D, Professor of Psychology, Lucknow University, Lucknow.

126. SEYMOUR SEWELL, LT-COL R. B, C I E, M A, Sc D, F R S, M R C S, L R C P., F Z S, F L S, Zoological Laboratory, Cambridge (1936)

127 SHORTT, LT-COL H E, I M S, Director, King Institute of Preventive Medicine, Guindy, Madras. (1936)

128 SIDDIQI, M R, M A, Ph D, Professor of Mathematics, Osmania University, Hyderabad (1937)

129 SINGH, B K, M A, Sc D, F I C, I E S, Professor of Chemistry, Science College, Bankipore, Patna

130. SINTON, LT COL J. A, V C, O B E, M.D, D Sc, D P H, D T M, I M S, Formerly Director, Malaria Survey of India, Downside, Windmill Lane, Epsom, Surrey, England.

131 SIRCAR, A C, M A, Ph D, Professor of Chemistry, Presidency College, Calcutta (1937)

132 SOKHEY, LT-COL S. S., M A, M D, D T.M & H, I M S, Director, Haffkine Institute, Parel, Bombay

133. SOPARKAR, M B, M D, B Hy, Medical Officer, Plague Research Inquiry, Indian Research Fund Association, King Institute of Preventive Medicine, Guindy, Madras. (1937)

134 SPENCER, E, D Sc, Ph D, F I C, A R.S M, M I M M, F G S, Consulting Chemist, Bird & Co, Chartered Bank Buildings, Clive Street, Calcutta

135 SRIVASTAVA, P L, M A, D Phil, Reader in Mathematics, Allahabad University, Allahabad (1935)

136 SUBRAHMANYAN, V, D Sc, F I C, Professor of Biochemistry, Indian Institute of Science, Bangalore

137. SULAIMAN, THE HON'BLE SIR S M, Kt, M.A, LL D, Judge of the Federal Court of India, New Delhi (1937)

138 TAYLOR, COL. J, C I E, D S O, M D, D.P H, I M S, Director, Central Research Institute, Kasauli (Simla Hills).

139 TEMPLE, F C, (Hony Col) A F (I), C I E, V.D, A D.C, 28 Victoria Street, London, S W. 1 (1937).

140 TIRUMURTI, T S, Rao Bahadur, B A, M B & C M, D T M & H, Professor of Pathology, Medical College, Vizagapatam.

141 TREVOR, SIR GERALD, Kt, C I E., Formerly President, Imperial Forest Research Institute, Dehra Dun

142 UKIL, A C, M B, M S P E, Tuberculosis Research Officer, All-India Institute of Hygiene and Public Health, Calcutta. (1935)

143 VENKATARAMAN, T S, Rao Bahadur, B A., I A S, Imperial Sugar Cane Specialist, P O Lawley Road, Coimbatore

144 VENKATESACHAR, B, Rao Bahadur, M A, F Inst P., Professor of Physics, Central College, Bangalore

145 VIJAYARAGHAVAN, T, Ph D (Oxon), Reader in Mathematics, Dacca University, Ramna, Dacca

146 VISWANATH, B, Rao Bahadur, F I C., Offg Director, Imperial Agricultural Research Institute, New Delhi

147 WADIA, D N, M A, B.Sc, F G.S, F R G S, F.R A S B, Geologist, Geological Survey of India, Indian Museum, Calcutta

148. WARE, F, C I.E, F R C.V S, I V.S, Director, Imperial Institute of Veterinary Research, Muktesar-Kumaun (U P).

149 WEST, W D., M A (Cantab), Geologist, Geological Survey of India, Indian Museum, Calcutta

150. WHEELER, T S, Ph.D, F R.C Sc I., F I C, F Inst P., M.I Chem.E., Principal, Royal Institute of Science, Mayo Road, Fort, Bombay 1.

151. WRAIGHT, E A, C I E, A R S M, M I M.M, F I C, Metallurgical Inspector, Jamshedpur

HONORARY FELLOWS

1 PROF. NIELS BOHR, N L, 15 Blegdamsvej, Copenhagen
2. PROF. LUDWIG DIELS, Director General of the Botanical Garden and Museum, 7 Königin Luise Strasse, Berlin-Dahlem, Germany
3 PROF F G DONNAN, F R S, Formerly Director, Sir William Ramsay Laboratory, University College, 23 Woburn Square, London, W C 1
4. PROF ALBERT EINSTEIN, N L, Princeton University, New Jersey, U S A
5. SIR JAMES G FRAZER, O M, D C L, LL D, Litt D, the Albemarle Club, London
6 SIR THOMAS H HOLLAND, K C S I, K C I E, D Sc, F R S, Principal of the University of Edinburgh
7 SIR FREDERICK GOWLAND HOPKINS, Kt, M A, D Sc, N L, F R S, Sir William Dunn Professor of Biochemistry in the University of Cambridge
8. SIR ARTHUR B KEITH, M D, F R C S, LL D, F R S, Buckston Browne Farm, Downe, Farnborough, Kent, England
9. SIR GUY A. K MARSHALL, C M.G, F R S, Director, Imperial Institute of Entomology, London.
10 PROF. ROBERT ROBINSON, D Sc, F R S, Waynflete Professor of Organic Chemistry in the Dyson Perrins Laboratory, Oxford University
11 SIR ALBERT C SEWARD, D Sc, Hon LL D, F R S, Formerly Master of Downing College and Emeritus Professor of Botany in the University of Cambridge, 209 Cromwell Road, London, S W 5
12. SIR CHARLES S SHERRINGTON, O M, G B E, N L, F R S, Formerly Waynflete Professor of Physiology in the University of Oxford, Broomside, Valley Road, Ipswich, England
13. DR. C. M. WENYON, C M G, C B E., F R.S, Director in-chief, Wellcome Bureau of Scientific Research, 183 Euston Road, London, N W 1

APPENDIX II.

ABSTRACT PROCEEDINGS OF THE COUNCIL, 1937.

[NOTE —These abstracts of the proceedings of the Council relate to questions dealt with which are likely to be of interest to Fellows. Routine matters and matters which are under consideration are not included]

1. The Council considered a letter from the Government of India regarding suggestions for the agenda of the General Assembly of the International Council of Scientific Unions. (No. 5—19-4-37)

(*Note* .—A reply was sent to the Government of India proposing that the General Assembly may be requested to reconsider the method of determining the contributions to be paid by adhering countries which are at present fixed on a population basis)

2. The views expressed by members of Council on the letters from the Indian Academy of Sciences regarding (*a*) printing of the names of the representatives of the co-operating Academies on the covers of the Institute's publications, and (*b*) modification of the rules to permit the appointment of persons who are not Fellows of the National Institute as representatives of the co-operating Academies on the Council of the Institute were considered (No. 5—26-7-37)

(*Note* .—The Council resolved: (*a*) to print the names in future in alphabetical order in each case and without indication of the Institution represented, and (*b*) that it is not desirable to have on the Council of the Institute persons who are not Fellows of the Institute, even as representatives of the co-operating Academies)

3. The opinions of members of Council regarding the modification to rules to permit the appointment of a representative of the Government of India on the Council of the Institute were considered. (No. 4—27 8-37)

(*Note* :—The Council resolved that in future only 24 members of Council be elected annually, the 25th place being filled by the appointment of a representative of the Government of India from among the Fellows of the Institute in accordance with the provisions of Rule 44)

4 The Council considered Prof V. Subrahmanyan's letter regarding the mode of election of the Council of the Institute (No. 8—27-9 37)

(*Note* —A Committee consisting of Prof M N Saha, Prof J N Mukherjee, Mr W D West, Dr A M. Heron and Prof. S P Agharkar was appointed to consider the question and suggest suitable alterations to Rule 48, for consideration of the Council.)

APPENDIX III.

COMMITTEES, 1938.

SECTIONAL COMMITTEES.

(1) 'Mathematics' Committee for Mathematics, Astronomy and Geodesy —

	To serve until Dec 31
Prof C V H. Rao	1938
Prof N R Sen (Secretary and Convener)	1938
Prof K Ananda Rao	1939
Lt -Col E A Glennie	1939
Principal G. S. Mahajani	1940.
Principal B M Sen	1940.

(2) 'Physics' Committee for Physics and Meteorology :—

Dr Nazir Ahmad	1938
Dr C W B Normand	1938
Prof B Venkatesachar	1939
Prof D M Bose (Secretary and Convener)	1939
Dr. D. S Kothari	1940
Prof. S. K Mitra	1940

(3) 'Chemistry' Committee for Pure and Applied Chemistry —

Prof. S. S Bhatnagar	1938
Sir Bryce Burt	1938.
Prof. V. Subrahmanyan	1939
Prof. J. N Mukherjee (Secretary and Convener)	1939
Prof. B. B Dey	1940.
Prof. J. C Ghosh	1940.

(4) 'Engineering Sciences' Committee for Engineering, Metallurgy, Electro-technics and kindred subjects .—

Mr. W. C. Ash	1938
Mr. F N Mowdawalla (Secretary and Convener)	1938
Mr. W E. V. Abraham	1939
Mr. E S Pinfold	1939.
Dr. G. Fowler	1940.
Dr. E Spencer	1940.

(5) 'Geology' Committee for Geology, Palæontology, Mineralogy and Geography .—

Mr. B. Rama Rao	1938.
Dr. A. M. Heron (Secretary and Convener)	1938.
Mr. D. N. Wadia	1939.
Mr. W. D. West	1939.
Dr M. S. Krishnan	1940.
Dr. F. G. Percival	1940.

(6) 'Botany' Committee for Pure and Applied Botany, Forestry and Agronomy :

Dr. W Burns	1938
Prof P Parija	1938
Mr H G Champion	1939
Prof K C Mehta	1939
Dr S L Ghose	1940
Prof S P Agharkar (Secretary and Convener)	1940

(7) 'Zoology' Committee for Pure and Applied Zoology and Anthropology including Ethnology —

Khan Bahadur M Afzal Husain	1938
Dr B Prashad (Secretary and Convener)	1938
Dr B S Guha	1939
Dr H S Pruthi	1939
Prof G Matthai	1940
Dr B Sundara Raj	1940

(8) 'Physiology' Committee for Animal Physiology, Pathology, Bacteriology Psychology and other Medical and Veterinary subjects —

Col J. Taylor	1938
Mr F Ware	1938
Bt -Col R N Chopra (Secretary and Convener)	1938
Prof W Burridge	1939
Dr R B Lal	1939
Prof N N Sengupta	1939
Dr A C Ukil	1940
Lt -Col H E Shortt	1940
Lt -Col. S S Sokhey	1940

APPENDIX IV.

LIST OF INSTITUTIONS ON THE EXCHANGE LIST

Indian

Allahabad

1 Allahabad University
2 National Academy of Sciences, India.

Bangalore

3. Department of Agriculture, Mysore State
4. Electrical Engineering Society
5. Geological Survey Department, Mysore State
6 Meteorological Department, Mysore State.
7. Indian Academy of Sciences
8. Indian Institute of Science.
9. Society of Biological Chemists, India.

Bombay.

10. Anthropological Society of Bombay.
11. Bombay Natural History Society
12. Indian Central Cotton Committee.
13. Royal Institute of Science.

Calcutta.

14 Royal Agri-Horticultural Society of India
15. Anthropological Society of India.
16. Biochemical Society of India.

17 Botanical Survey of India
18 Calcutta Mathematical Society
19 Calcutta Medical Club
20 Calcutta University
21 Carmichael Medical College
22 Geological Mining and Metallurgical Society of India
23 Geological Survey of India
24 Indian Association for the Cultivation of Science
25 Indian Chemical Society
26 Indian Medical Gazette—(Thacker Spink & Co (1933) Ltd)
27 Indian Physical Society
28 Indian Psychological Association
29 Indian Statistical Institute
30 Indian Tea Association
31 Institution of Chemists India
32 Mining and Geological Institute of India
33 Physiological Society of India
34 Royal Asiatic Society of Bengal
35 Science and Culture
36 Survey of India Department
37 Zoological Survey of India

Coimbatore

38 Indian Botanical Society

Conoor

39 Pasteur Institute of Southern India

Dacca

40 Dacca University

Dehra Dun

41 Board of Management Indian Forester
42 Imperial Forest Research Institute

Hyderabad (Deccan)

43 Department of Mines and Geological Survey H E H Nizam s Government
44 Osmania University

Indore

45 Institute of Plant Industry

Kasauli

46 Central Research Institute
47 Indian Journal of Medical Research
48 Malaria Survey of India

Lahore

49 Punjab University

Lucknow

50 Indian Zoological Memoirs

Madras

51 King Institute of Preventive Medicine
52 Madras Fisheries Department
53 Madras Government Museum

Muktesar.

54 Imperial Veterinary Research Institute

Naggar (Punjab)

55 Himalayan Research Institute, Roerich Museum

New Delhi.

56 Imperial Council of Agricultural Research

Poona

57 India Meteorological Department.
58 Indian Mathematical Society

Ranchi

59 Indian Lac Research Institute

Simla

60 Himalayan Club

Foreign

Canada

61 Department of Mines, Ottawa
62 Geological Survey of Canada, Ottawa

China

63 National Agricultural Research Bureau, Nanking.

Germany

64 Chemisches Zentralblatt, Berlin

Great Britain

65 British Museum, Natural History Section, London
66 Imperial Bureau of Plant Genetics (for crops other than Herbage), Cambridge
67 Imperial Bureau of Plant Genetics (Herbage plants), Aberystwyth
68 Nature, London
69 Patent Office, London
70 Royal Botanic Gardens, Edinburgh
71 Royal Society of Edinburgh
72 Science Museum, London

Java

73 Departement van Economische Zaken, Batavia

Uganda

74 Geological Survey of Uganda.

U.S.A.

75 American Chemical Society, Columbus, Ohio
76. American Museum of Natural History, New York
77. Marine Biological Laboratory, Woods Hole, Mass
78 Scripta Mathematica, New York
79 Treasury Department, U.S. Public Health Service, Washington
80. U S Department of Agriculture, Washington

APPENDIX V.

LIST OF PERIODICALS RECEIVED IN EXCHANGE OR AS PRESENTATION.

Indian

Agriculture and Livestock in India
Annual Report of the Indian Central Cotton Committee
Annual Review of Biochemical and Allied Research in India.
Bulletin of the Indian Central Cotton Committee
Bulletin of the Calcutta Mathematical Society.
Bulletin of the Geological, Mining and Metallurgical Society of India
Bulletin of the Hyderabad Geological Survey
Bulletin of the Institute of Plant Industry, Indore
Bulletin of the Madras Government Museum
Bulletin of the Mysore Coffee Experiment Station
Bulletin of the Mysore Geological Department
Calcutta Medical Journal.
Circulars of the Mysore Department of Agriculture
Detailed Report of Experimental and Research Work, Institute of Plant Industry, Indore
Extracts from the Proceedings of the British Empire Forestry Conference, South Africa
General Report of the Survey of India
Indian Forest Records
Indian Forester
Indian Journal of Agricultural Science
Indian Journal of Veterinary Science and Animal Husbandry
Indian Medical Gazette
Indian Physico-Mathematical Journal
Indian Zoological Memoirs
Journal of the Anthropological Society of Bombay
Journal of the Geological Institute, Presidency College, Calcutta
Journal of the Hyderabad Geological Survey
Journal of the Indian Chemical Society
Journal of the Indian Institute of Science, Bangalore
Journal of the Indian Mathematical Society.
Journal of the Indian Medical Association
Journal of the Osmania University College, Hyderabad
Journal of the University of Bombay.
Magnetic, Meteorological and Seismological Observations made at Bombay and Alibag
Memoirs of the Geological Survey of India
Memoirs of the Indian Meteorological Department
Mysore Agricultural Calendar
Nagpur University Journal
Palæontologia Indica
Proceedings of the Indian Academy of Sciences, Bangalore.
Proceedings of the National Academy of Sciences, India
Proceedings of the Society of Biological Chemists
Progress Report of the Institute of Plant Industry, Indore
Quarterly Journal of the Geological, Mining and Metallurgical Society of India.
Records of the Geological Society of India
Records of the Malaria Survey of India
Records of the Mysore Geological Department.
Report of the Botanical Survey of India.
Report of the Haffkine Institute, Bombay.
Report of the Institute of Plant Industry, Indore
Report of the Madras Fisheries Department.
Science and Culture.
Scientific Monographs of the Imperial Council of Agricultural Research
Scientific Notes of the Indian Meteorological Department
Statistical Leaflets of the Indian Central Cotton Committee.
Summary Proceedings of the Meetings of the Indian Central Cotton Committee.
The Mathematics Student.
Transactions of the Mining and Geological Institute of India.

Foreign.

Annual Report of the Geological Survey Department of Uganda.
Biological Bulletin of the Marine Biological Laboratory, Woods Hole, Mass., U S A
Berichte der Deutschen Chemischen Gesellschaft, Berlin
Bulletin of the Canada Department of Mines
Collected Reprints of the Woods Hole Oceanographic Institute.
Experiment Station Record, U S Department of Agriculture, Washington
Himalayan Journal
Journal of the American Chemical Society
Memoirs of the Canada Department of Mines
Notes from the Royal Botanic Gardens, Edinburgh
Proceedings of the Royal Society of Edinburgh
Papers in Physical Oceanography and Meteorology, Woods Hole Oceanographic Institute
Patent Office Library—Subject Lists, London
Report of the National Agricultural Research Bureau, Nanking
Report of the Canada Department of Mines
Scripta Mathematica, New York
Symposium of the All Union Scientific Research Institute of Economic Mineralogy, Moscow
Transactions of the Edinburgh Meeting of the International Union of Geodesy and Geophysics
Transactions and Proceedings of the Botanical Society of Edinburgh
Transactions of the All-Union Scientific Research Institute of Economic Mineralogy, Moscow

APPENDIX VI.

THE NATIONAL INSTITUTE OF SCIENCES OF INDIA.

Receipts and Payments Account for the year ended 30th November, 1937.

RECEIPTS	Rs.	A.	P.
To Balance brought forward	39,691	14	9
,, Members' Admission Fees	224	0	0
,, ,, Subscriptions	5,155	0	0
,, Donations	1,300	0	0
,, Contributions towards publication of 'Indian Science Abstracts'	600	0	0
,, Sale of Author's extra copies and publications	780	8	0
,, Sale of 'Indian Science Abstracts'	168	2	6
,, Interest on Investments	1,288	7	0
,, Miscellaneous Receipts	2	0	0
TOTAL	49,210	0	3

PAYMENTS		Rs.	A.	P.	Rs.	A.	P.
By Salaries of Staff					2,589	8	0
,, Printing Circulars, Notices, etc					101	4	0
,, ,, Publications, Report, etc					6,400	10	6
,, ,, 'Indian Science Abstracts'					1,714	12	0
,, Contributions to other Science Academies under Rule 19					972	0	0
,, Postage					570	4	9
,, Stationery					150	14	6
,, Office Equipment					397	0	0
,, Donation to Indian Science Congress Jubilee Fund					250	0	0
,, Audit Fees					50	0	0
,, Miscellaneous Expenses					175	3	3
,, Bank Charges					21	3	0
,, Cash and other balances—							
Investments—	Rs.						
3½% G.P. Notes 1842/43	5,000						
3½% ,, 1854/55	2,000						
3½% ,, 1865	6,000						
3½% ,, 1873	2,000						
3½% ,, 1900/01	8,000						
4% Loan 1960/70	10,000						
	33,000						
At cost		33,018	11	10			
With Imperial Bank of India—	Rs A. P.						
On Savings Bank Account	2,089 9 0						
On current Account	700 15 5						
		2,790	8	5			
In hand		8	0	0			
					35,817	4	3
TOTAL					49,210	0	3

Examined with the Books and Vouchers and found in accordance therewith.

PRICE, WATERHOUSE, PEAT & CO.
Chartered Accountants,
Registered Accountants. } *Auditors.*

CALCUTTA,
3rd December, 1937

APPENDIX VII.

BUDGET ESTIMATE FOR 1937-38

	1936 37 Estimates	1936-37 Actuals	Budget Estimate for 1937-38
Ordinary Receipts			
	Rs	Rs	Rs
Subscription	5,000	5,155	5,200
Interest	1,150	1,288	1,200
Contribution for publication of Indian Science Abstracts (including Annual subscription)	1,200	600	500
Sale of Publications	250	949	500
Grants-in aid		1,300*	
Grant-in-aid from the Government of India for 1937-38 and 1938-39			12,000
Miscellaneous		2	
Contribution from General Fund	5,850	4,099	
	13,450	13,393	19,400
Extraordinary Receipts			
Admission Fee	320	224	320
Ordinary Payments			
Salaries and allowances	2,700	2,590	2,700
Publications	8,000	8,217	9,000
Contributions to Science Academies under Rule 19	1,000	972	1,000
Furniture	500	397	500
Postage	700	570	600
Stationery	200	151	150
Auditor's fee	50	50	50
Miscellaneous	300	446†	600
Refunded to the General Fund			4,800
	13,450	13,393	19,400
Extraordinary Payments.			
Funding of Admission Fee and Donation	320	224	320

* Includes Rs 300 for 1937 38

† This amount includes a contribution of Rs 250 to the Silver Jubilee Session of the Indian Science Congress

Presidential Address.

CALCUTTA, 1938

By PROF M N SAHA, *D Sc*, *F R S*, *F R A S B*

THE PROBLEM OF INDIAN RIVERS

CONTENTS

I GENERAL

Meetings of the Institute

Since our last Annual Meeting held at Hyderabad [under Brigadier Sir Harold Couchman] we have, in pursuance of a general plan adopted last year by the Council, held a number of meetings in different cities of India. A meeting was held during the Easter holidays at Allahabad, this was followed by a symposium on the 'Malaria Problem in India' at Calcutta on the 27th and 28th August, 1937 at the All-India Institute of Hygiene and Public Health The symposium was attended by a large number of medical and scientific workers from all parts of India Considering the large number of papers contributed and the high level of the discussions, it may be considered to have been a great success We also held on the 6th November, 1937, a meeting at Delhi which was attended by Fellows living in Northern India We hope that in future meetings will be organized in other parts of India as well and that such meetings will lead to a fruitful exchange of ideas amongst scientists living in different parts of this continent and engaged in different pursuits.

Publications

We have continued the publication of the Proceedings, the Transactions, and the Indian Science Abstracts two parts of which for the year 1935 have already been published On the occasion of the Silver Jubilee of the Indian Science Congress, a Report on the Progress of Scientific Research during the last twenty-five years has been prepared, and this will be followed by our Annual Reports on the Progress of Science in India. This will complete the series of our publications We have to thank our general editor, Dr Baini Prashad, for the meticulous care with which he has edited these publications

Financial Problems

Financial problems have been a source of anxiety to our Council Scientific bodies like ours can never be self-supporting Our proto-type, the Royal Society of London, gets a grant of about £8,000 from the Government of the United Kingdom towards its publications. In the first year of our existence we applied to the Government of India for an annual grant We are glad to announce to you that the Government of India has sanctioned an annual grant-in-aid of Rs 6,000 commencing from the financial year 1937-38. Our grateful thanks are due to the authorities for this grant This grant has, for the time being, relieved to some extent our difficulties, but it is not sufficient to meet all our requirements. The excellent get-up of our publications has naturally encouraged our Fellows to send their papers in increasing numbers to the Institute, and this has added to our burdens

Need for a Permanent Office

Up to this time, we have been helped by the Royal Asiatic Society of Bengal which has very generously placed at our disposal an office room in their premises. Owing to increase in the work of the Institute, this accommodation is proving insufficient, and the Council will soon have to consider the question of finding suitable accommodation elsewhere

This year, the Institute has suffered severe losses by the death of several distinguished Fellows

Dewan Bahadur Anantakrishna Iyer

Dewan Bahadur Dr. L K Anantakrishna Iyer, one of our Foundation Fellows, who died on the 26th February, 1937, in his native village of Lakshminarayanpuram, Palghat, at the age of 75, was one of a small band of distinguished Indians who did pioneering work in Indian Anthropology Dr Iyer made his mark in Anthropology with two volumes on the Cochin Tribes and Castes, which he published in 1909 while Curator of the Museum at Trichur and Superintendent of Ethnography of the Cochin State. His great reputation as an anthropologist led to his being invited by the late Sir Asutosh Mukherjee to organize the Department of Anthropology of the Calcutta University. He has enriched Indian Anthropology by many contributions and by his death India loses a pioneer who made the civilized world familiar with the habits and customs of some primitive tribes of India

Sir Jagadish Chandra Bose, D.Sc., F.R.S.

Late during the last year we had to mourn the loss of Sir Jagadish Chandra Bose, one of our Foundation Fellows He was the first Indian to attain international reputation and that by virtue of his scientific work The present generation of Indian scientists can have very little idea of the struggles of our early pioneers of Science, Sir J C Bose and Sir P C Ray, for it happens very frequently that those who eat the cake are very apt to forget those who ground the corn and kneaded the dough for them As my friend Dr Birbal Sahni has put it '—'An incredibly long period of degradation separated us from a great and proud past. Indians were known only as dreamers and philosophers, their right to be heard as scientists was only laughed at India will for ever remember Sir J. C Bose as the pioneer who broke this spell ' Early in the nineties of the last century Bose, while a subordinate professor of physics at the Presidency College, Calcutta, was inspired by the researches of Hertz in Germany, who, following Maxwell's theoretical works, had produced electro-magnetic waves in the laboratory With crude apparatus of his own design and without guidance from any quarter, and amidst innumerable difficulties, Dr Jagadish Chandra Bose, then 36 years of age, repeated all the experiments of Hertz, at the laboratory of the Presidency College, Calcutta Further, with the aid of ingenious apparatus of his own design, he produced extremely short electro-magnetic waves, which closed the gap between light waves and electric waves He was one of the first to realize and perform experiments proving that Hertzian waves can be used for the propagation of signals, but in this work he was forestalled by the young Italian Marconi With a little more luck and a better environment, he might have gone down to history as the discoverer of Wireless Telegraphy Later in life, he turned his attention to the solution of a great problem, namely the Problem of Life , how inanimate atoms combine to form substances which give rise to the phenomenon of life This problem, so long the theme of innumerable speculations by magic men, founders of religions and philosophers, was for the first time attacked in an entirely novel way, viz with the aid of physical instruments He devised marvellously sensitive physical instruments (e g the Magnetic Crescograph) for recording the phenomenon of growth decay, and death due to natural as well as to artificial causes, and also for solving other associated phenomena, such as for example the ascent of sap in plants Though his conclusions have not in general been accepted, it will be conceded at all times that he tackled a great problem from an entirely new and probably the only point of view which is likely to lead to success Probably this problem will be nearing solution after the discovery of Induced Radioactivity, and attacks on the problem of life by physical methods have been started by Profs Bohr, Krogh, and Von Hevesy at Copenhagen, and the Curie-Joliots at Paris If the problem is ever solved the scientific world will probably remember that it was an Indian savant who first conceived it.

We have also suffered very heavy losses in our Honorary Fellows. Lord Rutherford of Nelson whose loss we mourn to-day was elected our Foundation Honorary Fellow in 1935. We all expected that he would be present here this week and guide the deliberations of the Silver Jubilee of the Indian Science Congress. But it is an irony of fate that we have to mourn his loss to-day, and the address, which is the last written work of the great scientist, has to be read by Sir James Hopwood Jeans, who agreed to preside in his place Lord Rutherford was the foremost among the experimental physicists of the present time and probably of all times and his place is in the same company with Faraday and Newton As the discoverer of the law of spontaneous disintegration of radioactive atoms, of the nuclear theory of atoms and as the pioneer who was the first to realize the mediæval alchemists' dream of transmutation of elements, Rutherford has for all times an assured place in the Hall of Immortals. His influence spread so rapidly that he easily attained leadership amongst British and international men of science, a leadership which he utilized for the benefit of his country and of the world

Lord Rutherford of Nelson, O.M., F.R.S., Nobel Laureate

In this connection, I may be permitted to add a few personal reminiscences. I visited Cambridge in June, 1936 and had the privilege of interviewing Lord Rutherford at the Cavendish Laboratory. The offer of the Indian Science Congress Association and the British Association to preside over the joint session (Silver Jubilee Session) had just then been communicated to him, but he was still hesitating in his mind whether to accept or reject the offer His main difficulty was, as he explained to me, that as he had no first-hand knowledge of affairs in India, he did not feel quite comfortable in accepting leadership on such a historic occasion. We had a long discussion—lasting for about an hour—and I conveyed to him as much information as possible, regarding the utility and needs of scientific research in India. We went very thoroughly into the existing state of scientific education and research, the scope of work of the existing research institutions, and the need for further and more efficient organization of research work in India for the service of the nation. He took notes about our conversation and it was a pleasant surprise when I found that almost half of his address which was read to us by Sir James H. Jeans was devoted to these topics His address is his last written work, and should be regarded as a message not only to Indian scientists but also to Indian administrators, public men and philanthropists It emphasizes, in the clear and concise language characteristic of Rutherford, the need for greater recognition and encouragement of Science by the State and the leaders of society.

Prof. Albert Heim, who was elected Honorary Fellow in 1936, died on August 31, 1937, at the ripe old age of about eighty-nine years. He was a very great man whose name is intimately connected with the structural interpretation of the Alps.

Prof. Albert Heim

Heim was Professor of Geology at the Polytechnic and at the University

in Zürich from 1873–1911. He was the author of a three-volume work on the Geology of Switzerland which is recognized as perhaps the finest national text-book ever written

Besides tectonics he was interested in many other aspects of Geology, particularly the glaciers

He was Director of the Swiss Geological Commission from 1894–1925, and was the recipient of honorary doctorates from Bern, Oxford and Zürich and was elected a Foreign Member of the Royal Society of London

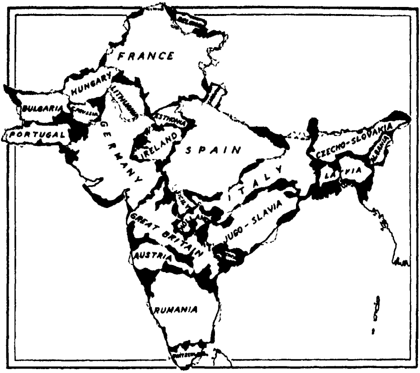
Our first President, Sir Lewis Fermor, laid down the rule that the President of the year should deliver an address dealing with the particular subject in which he has carried out original research in a way which will be quite comprehensible to scientists working in other lines If I follow this advice, I should deliver an address on Astro-Physics, a subject to which I have made some little contribution I have purposely refrained from attempting an address on this subject because we have this week two of the world's leading astro-physicists among us, viz Sir James Hopwood Jeans, the President of the Silver Jubilee Session of the Indian Science Congress, and Sir Arthur Stanley Eddington It appears to me that I shall be on safer grounds if in the presence of these distinguished astro-physicists, I talk on a subject to which to the best of my knowledge, they have not contributed anything and are not likely to contribute anything I would like to invite the attention of the scientists gathered here to a problem of practical scientific importance on which the welfare of millions of our countrymen depends It is about the problem of Indian rivers. My address would be an introduction to the symposium on River Physics which has been organized under the joint auspices of the National Institute of Sciences, the Indian Science Congress, and the Indian Physical Society I have to thank the other distinguished scientists, geologists, zoologists, engineers and mathematicians who have generously responded to my invitation

II PROBLEM OF INDIAN RIVERS.

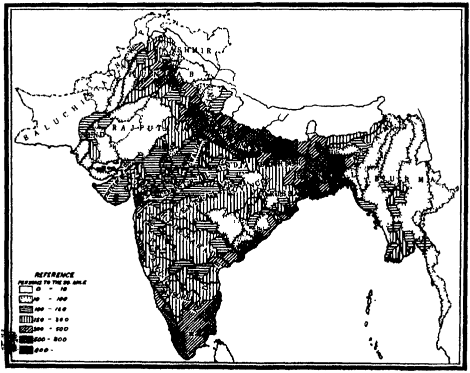
1. *Introduction.*

Indian Civilization mainly a River Valley Civilization

You would probably like to know why I chose this particular subject for my address I have on the screen two maps of India (Maps 1 and 2), the first, which I have reproduced from Sir L L Fermor's presidential address to the Indian Science Congress in 1932, shows that India is vast enough to accommodate all the countries of Europe except Russia The second is a population map of India You will observe from this that the Indian population is still mainly concentrated in the valleys of the great rivers which intersect this continent. With a few exceptions, the great cities which are centres of industry, culture and administration are mostly to be found on the banks of the great rivers. If we go back in


FRANCE
HUNGARY
BULGARIA
LITHUANIA
PORTUGAL
GERMANY
ESTHONIA
IRELAND
SPAIN
ITALY
CZECHO-SLOVAKIA
GREAT BRITAIN
AUSTRIA
JUGO-SLAVIA
RUMANIA

Map 1


KASHMIR
BALUCHISTAN
BURMA
REFERENCE
PERSONS TO THE SQ. MILE
0 - 10
10 - 100
100 - 150
150 - 300
300 - 500
500 - 800
800 -

Map 2.

time and survey our past history, which can now be traced to 4,000 years before Christ, we shall find the same story, my own studies in the history of our country have confirmed me in the belief that even 200 years ago, there was a very scanty population in the country away from the banks of the great rivers.

Rivers essential for agricultural communities

In fact, this condition is not peculiar to India Human civilization on this globe of ours has, since time immemorial, chiefly centred about rivers and river basins Who can conceive of Egypt without the Nile, of ancient Sumer and Babylon without the Tigris and the Euphrates, and of China without the Hoang-ho (the Yellow River) and the Yangtsekiang? The early growth of settled human life in river basins is to be ascribed to the fact that rivers supplied the largest amount of needs of early societies which were mainly agricultural They supplied them with the all-important water for drinking, bathing and other domestic uses and for irrigating their fields Rivers also formed the indispensable highway of communication before the discovery of the steam locomotive Since rivers were so important to human life in its early stages of cultural development, convenient sites on them used to draw large populations and such sites gradually grew to be great cities and capitals of mighty empires

New Pathways of Human Activity

The rise of maritime civilizations like those of Greece (centred round the Aegean Sea) and of Rome (centred round the Mediterranean Sea), which was due to the extension of human activity away from riparian tracts, did not at all diminish the importance of rivers, though development of maritime activities gave rise to new centres of population like sea-ports But these were generally clearing houses for the country products, which were produced in riparian tracts In modern times, the growth of large-scale human activities and of the factory system has given birth to new centres of population which are in many cases away from rivers, but as the largest part of humanity has still to depend on agriculture, the rivers have not lost their importance to mankind Moreover, in recent times, in addition to agriculture, novel use has been found for rivers In the first place, for convenient and cheap transport of goods it has been found that no other method of communication can beat river transport Secondly, some of the rivers, if properly harnessed, can supply electrical power which is all important for the development of industry and for other human needs in the present century.

2 *Rivers need attention*

Irrigation an ancient art

The importance of rivers may be gauged from such phrases as 'Egypt is the gift of the Nile' But experience has also shown and this was also known to early human communities that rivers need attention. First of all, there is the annual

cycle, during one season of the year the rivers are filled to the brim with water, sometimes overflow the banks, and inundate the fields Then comes the lean period when they almost run dry. The ancient peoples found that if these phenomena could be controlled, the rivers could be made to do more good than if they were left to themselves Out of these considerations rose the art of irrigation, one of the oldest ever practised by the human community

Irrigation in ancient countries

Irrigation in different ways was practised on a stupendous scale in Egypt, Babylon, old China, as well as in India In fact, the existence of the community depended upon the successful practice of irrigation In Mesopotamia, the two rivers run through a desert country and only a small fringe of land, on either side of each river, is directly accessible to river water But the ancient dwellers of the land, the Sumerians, five thousand years ago, cut canals from the rivers and irrigated their fields, which were away from the immediate reach of the rivers In fact, but for the net-work of irrigation canals with which the whole land was intersected, very little of the country would have been habitable Elaborate precautions were taken by the State for maintaining the canal system from the attacks of external enemies and from the harmful effect of internal quarrels This magnificent canal system was the cause of the great prosperity of ancient Iraq, up to 1258 A D, when the Mongols under Hulagu Khan conquered the country, and systematically destroyed the canal system by blocking the mouths of canals and allowing them to fall into decay Iraq, which up to the 13th century, contained the greatest cities of those times in the world (e g Baghdad) and was farfamed for its culture and prosperity, has never recovered from this catastrophé

Modernization of Egyptian Irrigation

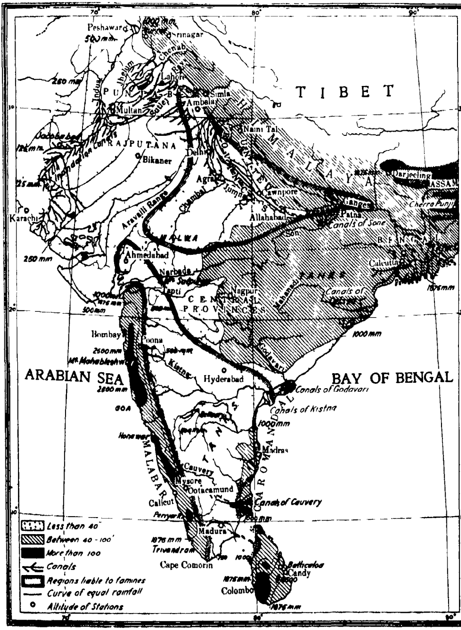
While the Babylonians practised perennial irrigation, the Egyptians practised 'Basin Irrigation' from time immemorial They anxiously waited for the Nile to overflow its banks which it did with clocklike regularity, and then held up the water by throwing earthen mounds round their fields In recent years, basin irrigation, which allowed only one crop to be grown in the year, has been converted to 'perennial irrigation' by the construction of the Assouan and other dams across the Nile. This has allowed Egypt to raise two to three crops in the year.

3. *Irrigation in Ancient India*

It is well known to every reader of history that irrigation has been practised from time immemorial in India, but owing to the vastness of the country the system practised has not been uniform as in Egypt or Babylon During the troublesome days which ensued after the weakening of the Mughal dynasty about 1740 A.D., and the re-establishment of settled rule under the British about 1800 A.D., most of these ancient systems had fallen into decay, but sufficient had subsisted to enable us to form an idea of the way in which irrigation was practised in different parts of the country.

Diversity of Indian Irrigation in former times

I place before you an Irrigation Map of Modern India (Map 3), just to illustrate the particular features of irrigation in different parts of the country. First of all, there are the arid areas of Sind and Southern Punjab which receive very little rainfall Then come the precarious areas (areas of scanty rainfall)



MAP 3.
(Adopted from *Geographie Universelle*, Tome IX, 1929.)

of the Punjab. Here, in ancient times, water was tapped by canals which were cut off from the banks of the rivers. The canals were filled with water only during floods The western part of the Ganges valley does not suffer so much from defect of rainfall, but there are wide tracts in this part which are far away from the banks of the main rivers, and from which rainwater drains off quickly. The problem is to bring water to these areas by means of perennial canals Southern India again presents a different aspect In the centre it is a table-land, and the rain, which falls mostly within a short period, drains off quickly to the eastern sea. Ancient rulers held up the water by throwing dams across convenient sites on river courses, and thus creating reservoirs and artificial lakes from which water could be tapped for agricultural purpose whenever necessary This is sometimes known as storage or tank irrigation. Besides these areas, we have in India the lower basins of the rivers, where the flow is perennial, and the deltaic regions, where in addition the rainfall is abnormally large. These areas present quite different problems, but to these I will refer later on

The successful practice of irrigation demands organization, settled government and scientific knowledge. Were ancient Indians capable of attacking the problem on scientific lines ? To the western world, India was known as a land which for all ages has been full of unpractical dreamers and philosophers. It was a mild shock to the West when, in 1909, an old Sanskrit manuscript, Kautilya's 'Arthasastra', was discovered

This book reveals a different type of Indian mentality. Prof W E Clark, Head of the Department of Sanskrit at the Harvard University, says —

The practical Indian Mind in ancient times

'The discovery in 1909 of the Kautiliya-Arthasastra has opened up an entirely different world of life and thought in ancient India from that represented by the religious and philosophical literature of the Veda. Accounts of ancient Indian civilization based entirely on this religious literature are as misleading as would be accounts of early European civilization based entirely on the Church Fathers.

'The book deals with every phase of government as regulating all matters of worldly life—a government which was not dominated by the priesthood but which was highly practical and empirical Sections are devoted to precious stones, ores, metallurgy and mining, roads, trade routes and irrigation, medicine, trees, plant and poisons, ships and shipping, cattle, horses, and elephants, chemistry, mechanical contrivances, and other technical matters' (*Legacy of India* by Garret.)

Irrigation under the Mauryan Emperors

We learn from this book that the great Mauryan Emperors, who in the third century before Christ ruled over a land bigger than the present British Indian Empire, maintained a regular department of irrigation and navigation The officers looked after the maintenance of irrigation canals, levied

taxes on water, and controlled navigation An inscription found at Girnar in Kathiawar peninsula tells us that by the orders of the Emperor Asoka a great water storage tank called the Sudarshan lake was constructed by his Governor, the Persian Tusashpa, by throwing a masonry dam across a mountain pass. According to later inscriptions, it was twice repaired Once by the Saka Satrap Rudradaman (150 A D) and then by the Gupta Emperor, Skandagupta (460 A D) Southern India is full of huge storage tanks used for irrigation which testify to the ancient rulers' solicitude for the storage and judicious use of water

Another famous irrigation work was the Grand Anicut on the Cauvery river, where it begins to form a delta (see Map 3) This was constructed by the Hindu rulers of the First Century A D , and was in continuous use up to the 19th century, when it was repaired by Sir Arthur Cotton, the pioneer of large-scale irrigation in this country under the British régime

The Gangetic Delta

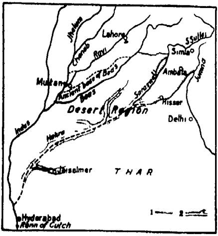
The riparian area of India consists, besides the regions mentioned above of the lower reaches of the rivers where they begin to form deltas The physical condition of these areas and the life of the rivers are quite different from those in the upper sections You will have some idea of these regions if you look at the delta of the Ganges river Up to Rajmahal, the Ganges receives only tributaries but below it the river flows through soft soil and divides itself into a labyrinth of channels The land is low and subject to inundations during the monsoon season There is a great difference of opinion as to whether the ancient rulers tried at all to prevent these rivers from leaving their beds, finding out new channels and eroding villages and cities, as we find them doing now.

4 *Long Period Changes in River Courses*

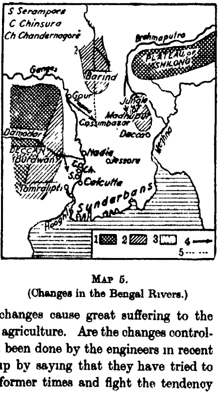
I have given you an imperfect sketch of the usual régime of rivers in ancient times Besides the periodic changes connected with seasons, certain long period changes in the course of rivers have been noticed by competent authorities, the cause of which is still hotly debated amongst Geologists, Surveyors and Historians. You may have an idea of these long period changes if you look at the two maps before you Map 4 represents the alignment of the Punjab rivers about two thousand years ago You will see from this that the Punjab rivers have a tendency to change their course and that they generally move west. There is a fight going on between the deserts and the river valleys The desert is constantly encroaching on the rivers and pushing them to the North-West. Is it due to some deep-seated tectonic action whose influence is accumulative or has there been a change in the course of the monsoon tracks of rain-clouds ? There can be no difference of opinion regarding the reality of these changes. The Archæological Department of the Government of India

The Punjab Rivers

has found, besides Harappa and Mahenjodaro, a large number of cities buried under the sands of Sind and Rajputana. These cities could not have existed unless there was more plentiful supply of water in these regions 5,000 years ago than is to be found now. It has been surmised that the North-Western monsoon, which gives the Punjab a certain amount of rainfall during winter and is very beneficial for wheat cultivation, used formerly to have a more southerly course, and passed over Sind and Rajputana. It is further supposed that the rivers of the Eastern Punjab used formerly to unite in a powerful course and flow in a separate channel, parallel to the Indus, to the sea, thus giving Sind all the advantages of a land between the two rivers, the Indus on the west and the Saraswati on the east. It is surmised that the lower course of the Saraswati ran dry during Vedic times and its original course is marked by a dry channel The other rivers have moved away from their courses generally to the west. What has been the causes of these changes in the courses of rivers which have taken place within historical times? My friend Mr. Wadia of the Geological Survey of India who deals more extensively with these matters tells us that many of the rivers are more ancient than the land, and surmises that these changes are due to crustal movements



MAP 4.
(Changes in the Punjab Rivers)



MAP 5.
(Changes in the Bengal Rivers.)

It goes without saying that these changes cause great suffering to the population which is mainly dependent on agriculture. Are the changes controllable at all? In fact the work which has been done by the engineers in recent times in the Punjab may be summed up by saying that they have tried to restore the waterways which existed in former times and fight the tendency of the country to aridification.

The Ganges-Brahmaputra System carries largest volume of water

When we turn to the deltas of the Ganges and the Brahmaputra (Map 5), we find that throughout historical periods, constant changes have been going on in the lower courses of these rivers, changes which have exerted a far-reaching influence on the economic and political condition of the countries through which they pass The total length of the Ganges is only 1,500 miles wholly in India and that of the Brahmaputra is 1,800 miles of which 800 miles are in India The length of the river courses may give one a false idea of the actual importance and the stupendousness of the geological changes caused by these rivers for though the Ganges is rather short compared with the other great rivers like the Yangtsekiang in China or the Mississippi in the U.S.A, careful measurements have shown that her peak discharge during the monsoon period exceeds that of the Mississippi and is seven times that of the Nile The discharge of the Brahmaputra is about one and a half times greater than that of the Ganges These circumstances, combined with the fact that they flow over a comparatively small region, have made these rivers unique objects of interest.

Recent changes of water courses in the Ganges-Brahmaputra Delta

This will be apparent from Map 5 which I am exhibiting before you This shows you the courses of the Ganges and the Brahmaputra rivers over the lower reaches only 150 years ago compared with their present courses You will see how great are the changes which the river systems have undergone. In fact, with respect to these lower deltaic regions, it can be said that the geography is changing markedly within the short period of a century. You find that some of the ancient water courses have entirely disappeared and new systems, which did not exist two hundred years ago, have come into existence The Ganges and the Brahmaputra 200 years ago used to discharge their waters by two separate courses which were about 150 miles apart from each other. There was a third system of water courses between these two which, flowing through Northern Bengal, used to discharge its water independently into the sea or into one of these two rivers But great changes occurred between 1787 and 1818, due to causes which are well known, and now the main streams of the Ganges and the Brahmaputra unite 200 miles inland. This has caused widespread changes in the topography and the economic life of these regions. These wide changes are characteristic of all the rivers in the whole of Bengal and in Assam and to a much lesser extent of the deltas of the Mahanadi river of Orissa. Are these changes partly due to some deep-seated forces or to the natural surface action of the rivers which, unable to carry their heavy load of silt, go on depositing it on their beds and banks, and are ultimately forced to seek new channels? Scientists will take a long time in answering such questions, but it is needless to say that these changes have caused great dislocation of human life—old cities have been eroded, prosperous country-areas

have been washed away, swamps have been formed and regions once populous have been ravaged by malaria. Can these changes be controlled at all?

5 *Problem of Deltaic Cities.*

Ruined Cities in Deltaic Areas

Besides causing widespread changes in rural areas, the deltaic rivers have played havoc with the ancient cities, results of centuries of patient and concentrated labour by ancient rulers and communities. Most of the ancient cities famous in tradition in this country and playing a great part in its political history grew on their banks, or on the banks of their tributaries Nobody has yet given a full and consistent account of the causes leading to the rise and growth of these cities, nor has told us how far the phenomena of the growth and decay of states connected with them were due to the action of the rivers We are usually apt to ascribe growth and decay of countries only to political causes, but a deeper probing into facts shows that this is not the whole story A few examples will show. Ancient Pataliputra which was the capital city in India from the 6th century B C to about the 5th century A.D —an interval of nearly a thousand years—owed its importance to its position as an important trade centre at the junction of 5 rivers (the Ganges, the Sone, the Ghogra, the Gandak and the Punpun, see *Science and Culture*, Vol 2) at a time when rivers were the main channels of communication It now lies buried under the present city of Patna at a depth of 17 feet below the ground level Its destruction was due, as authenticated historical tradition tells us, mostly to destructive floods It appears that in the deltaic regions, the level of a city gradually goes down while that of the surrounding country rises, so protective bunds have to be constructed to keep the flood water out But sometimes, particularly if the city is between two rivers, as was the case with Pataliputra, and there is simultaneous flood in the two rivers, these bunds give way, causing destructive floods and depositing thick layers of silt Modern excavations have shown that ancient Pataliputra used to be very often visited by floods, and ultimately disappeared under the silt deposit. It is quite probable that the disappearance of Magadhan supremacy after the 6th century A D in Indian politics may be due to the destructive action of rivers on the chief cities of Magadha which the rulers were unable to gauge and control

Those who have read the story of the discovery of the Indus Valley civilization in the sumptuous volumes published by the Archæological Survey of India are aware that many prosperous cities in the lower Indus Valley had to be deserted because they used to be very often visited by floods or the rivers changed their courses and deserted the cities The whole Indus Valley is full of dead sand-buried cities along the old course of the Indus. Another menace to great cities on river banks is the possibility of the formation of unhealthy swamps in the neighbourhood which may give rise to catastrophic epidemics. An example is

Destruction of Gaur

afforded by the story of the city of Gaur which from the 5th century A D to 1576 A D. formed the capital of Eastern India It was situated between two branches of the Ganges river, and another large tributary, the Mahananda, flowed near by A very unhealthy swamp grew in its rear on account of changes in the river course and, possibly due to the lowering of the city level, the drains in the cities could not discharge the sewerage to the rivers properly The result was the outbreak of an epidemic which swept away the majority of the population about the year 1575 and the vast city, which was estimated by the Portuguese merchants of the 16th century to contain a population of over two millions, now remains buried under an overgrowth of jungle

Calcutta may share the fate of Pataliputra and Gaur

A similar fate seems to be slowly overtaking the present city of Calcutta which is the successor of Pataliputra and Gaur as the premier city in Eastern India, its level has gone down within the two hundred years of its existence by about 2 to 4 feet below the level of the surrounding country and the drains from the city can no longer discharge their refuse matter to the surrounding river channels without pumping The problem of Calcutta's drainage has been before the public for a long time but no satisfactory solution has been found My friend, Mr S C Majumdar of the Irrigation Department has dealt exhaustively with this problem Will the citizens of Calcutta profit by his advice or allow their city to run to destruction like Pataliputra and Gaur? The case of Calcutta also confirms the belief that in deltaic regions the level of cities has a tendency slowly to go down, while that of the surrounding country gradually rises The result is that city sewerage does not flow through the drains, unless artificial methods are undertaken, and the city gradually becomes unhealthy In fact, as has been remarked, Calcutta may be buried in the near future in its own sewerage These slow changes therefore deserve more study and attention than spectacular catastrophes like a flood In fact, a look at the ruins of old cities in the deltaic regions is sure to produce the conviction that a satisfactory method of city-planning in such regions has yet to be evolved

6 *Modern Times*

When the administration of this country devolved upon the British nearly two centuries ago, the task of maintaining all the ancient irrigation channels and storage tanks and keeping the rivers in order fell on their shoulders From the very first the Government of India took the greatest amount of interest in irrigation work and it is estimated that a total capital of 150 crores of rupees has been invested in constructing new irrigation channels, building storage dams and repairing old works According to the report of the Central Irrigation Board, about 30 million acres of land in India are being irrigated by these artificial canals which total nearly forty thousand miles in length. Of these, 22 millions are officially regarded as productive and the remaining 8 millions have been officially admitted to be unproductive. We

have to consider whether the amount spent under irrigation has been sufficient, whether there is still room for improvement and expansion. What was the cause of a large percentage of works being unproductive ?

Further Scope for extension of Irrigation

On account of the peculiar orientation of the mountains and the seas, India is the recipient of a large amount of monsoon rainfall from the Bay of Bengal as well as from the Arabian Sea, within a short time. It is estimated that of the total rainfall on this continent, nearly 60 per cent gets evaporated, about 40 per cent passes through the river channels, and of this 40 per cent barely 6 to 8 per cent is utilized by the rural population for irrigating their fields. These figures alone show that in spite of large irrigation works already undertaken, there is still room for further expansion. The figure of 360 millions for the population of India may give the idea that India is over-populated, but the density of the population is only 200 per sq mile, which is much less than is the case in many other countries with less resources. A careful survey of the facts shows that there are large regions in India which still require extensive irrigation works for further development. If these regions can be developed, then probably a large part of the population can migrate from over-populated areas to these regions and thus relieve the existing congestion. A greater expansion of irrigation will also result in the production of more foodstuff and other economic products and give us a better standard of living We have further to consider in what way the existing arrangements can be improved so that a greater return may be obtained to the Government on the invested capital.

Railway Bridges over Rivers

A new factor was added to the problems already existing on account of the need which was felt in constructing bridges over these rivers About 80 years ago, railways began to be constructed in India and it was found necessary to span rivers by means of well-designed bridges capable of carrying heavy railway traffic Now the design of these bridges requires that the engineer should have a very accurate knowledge of the life of the rivers, its maximum and minimum discharge and their variations throughout the year, the nature of the soil and the total amount of precipitation in the basins over which the rivers pass They had also to find out how the construction of a bridge will obstruct free flow of water through the rivers and *affect the surrounding rural area* A further factor has arisen in recent times owing to the necessity of supplying the country with cheap sources of electrical power To this topic, however, we return later on.

7. *Need of more River Physics Laboratories.*

The earlier engineers who were entrusted with these tasks treated the problem as they thought best and without meaning any disrespect to these early pioneers, it may be said that their actions have not always been very beneficial to rural interests. It is of course quite correct that the

system of irrigation canals, which has been planned by the engineers within the last 100 years in the Punjab and the western parts of the United Provinces and parts of Madras and Bombay, has done immense good to the regions concerned and has brought prosperity and population to an otherwise waste area But the same cannot be said of the deltaic regions of Bihar, Bengal and Orissa and parts of C P which contain most of the unproductive irrigation works It appears that in the planning of canals, bridges and railway lines in these areas some very fundamental mistakes were committed The case was very ably summarized by Sir Francis Spring, *the founder of River Physics in India* While entrusted with the task of designing a bridge over the Ganges in Bengal, he went thoroughly into the problem and summarized the necessity of a River Physics Laboratory, in the following words —

'As trustees of so fine a property as this—canals and railways, it might not unreasonably be expected that the State would see the importance of devoting a comparatively small annual appropriation to original research, on lines likely to be productive of a good return for the expenditure, in the form either of reduction in the first cost of its public works or of their safety and their economical up-keep when built *Heretofore there has been no pretence of organizing any such research* in connection with the engineering of the canals and railways of India *Engineers have gone on blundering, benefiting, rather by chance than by design, by the experience of their predecessors, and each considering himself lucky if he escapes disaster at the hands of the tremendous forces of nature—amongst which some of the most potent for good or evil are the great rivers—with which he has to struggle.* Until quite recently there has been practically no encouragement, and indeed at times there has been discouragement, to men to publish their experiences And so, in spite of having perhaps as fine a body of scientific engineers as any country, not excluding France, has in its employment, and in spite of this body of public servants having carried out daring and extensive works of a certain character, chiefly, in connection with the great Indian rivers, on a scale unparalleled elsewhere, the State possesses the most meagre record of the history of the works carried out so successfully by its employees In putting the chapters of this book (*River Training and Control* by Sir F Spring) together, the author, found extreme difficulty in ascertaining what had been done, what difficulties had been encountered, and how these difficulties had been surmounted, and it has needed the expenditure of nearly a year of research to enable him to offer to the Government of India the advice, contained in the foregoing chapters, in regard to one limited phase of the engineering of great rivers Time will show the value of that advice, and doubtless further experience will modify the practice recommended. But meanwhile *the author would urge on the Government the importance, from a mere money point of view, of insisting on the maintenance of an intelligent record of the history of such works as those dealt with in the foregoing chapters.*'

The Consequence of lack of Organization

'With regard to the physics of long reaches of the great rivers, the author is not in so good a position to speak. His special experience has been gained rather on short lengths of such rivers in contiguity to his works In view of his practical inability to regulate the flow of great lengths of such rivers he has viewed the inimical consequences of the irregularities of their flow, in the form of deep and dangerous scour, as requiring to be fought by sheer irresistible force rather than by coaxing This necessarily must be the attitude of the engineer in charge of great bridges, and perhaps to a lesser extent of those in charge of great irrigation weirs But *they ought not, for that reason, nor ought the State, to lose sight of the importance of endeavouring, by consistent, logical and well-organized research, to learn something more definite than is now known about the physics of long reaches of rivers* A perusal of chapters III and XXI, as well as of Mr R. A Molloy's Technical Section paper No 118, will suffice to show how blindly, heretofore, in the interests of the residents on their banks, men have been fighting against the ill-will of some of the great rivers, whether on behalf of the maintenance of levees[1] whereby devastating floods are excluded from great inhabited areas, or for the conservation of the heads of inundation canals on whose integrity the welfare of many thousands of people is dependent, or *in the interests of riparian cities whose obliteration would be a blot on the administration of civilized and intelligent rulers It is difficult to avoid the conclusion, after perusal of chapter XXI, that for lack of adequate knowledge, the engineers concerned with the interests of the inhabitants of the valley of the Indus have been obliged to work more or less in the dark in their fight with that river, and to make matters worse it has constantly happened that, owing to the climate, to the exigencies of public service, no sooner does one engineer get some small inkling of the tricks than he is replaced by one with all his experience to gain, and in six months he, in turn, is replaced by somebody else whose experience of the river has perhaps been limited to crossing it How, under so haphazard a system, anything gets done at all is a marvel*, and instead of being surprised at £100,000 worth of work having been wiped out, the State may congratulate itself if the loss is not double. However there is always the satisfaction, in the case of such expenditure as that dealt with in chapter XXI, that the whole of the money has remained in the country, and that if the taxpayer takes money out of his coat pocket only to put it into his waistcoat pocket he can always pick it out again, or its equivalent.'

Suggestion for the appointment of a River Commission.

'*The appointment, for say 10 years, of a River Commission not merely for the Indus, but for the organized study of the physics of great alluvial rivers*

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[1] This is a word of French origin, which is used in the U.S.A. to denote embankments.

generally, would be a service to civilization and an act worthy of a great State. The Mississippi Commission have done a great deal, but their experience is not to any great extent applicable to Indian conditions. The experience of the engineers of the Rhone and the Danube and other European rivers, though valuable in its way, is even less applicable to India than that gained on the Mississippi. Mr R A Molloy's attempt at a theory, as summarized very inadequately in chapter III, is the first that can be characterized as a scientific generalization of the river problem that the author has heard of in India. And even this is based on inadequate data, picked up anyhow, amidst the multifarious duties falling to the engineer to a system of inundation canals. There is need for a thoroughly scientific location and for the automatic reading, of gauges at hundreds of places, for several years, along great lengths, selected with care and knowledge, of several of the great Indian rivers, also of some systematization of the surveys which usually are undertaken on these rivers, and of the making of fresh surveys specially designed to elucidate facts, also of an organized system of soundings and sections. The engineers in charge of the work must steadily keep in view the ultimate object of it, and must not make a survey merely for *the sake of a section. The object in view will be: To present to the scientific world, and especially to the engineering world, and more particularly to the engineers of structures in India that are subject to fury at the hands of the great alluvial rivers, such an explanation of the probable action of these rivers, under various circumstances, as will allow of such action being anticipated; and especially, to enable the engineer to utilize fully his knowledge of the rivers*, so that he may make a servant of it, instead of being as it is now very often the case, his master. There can be no doubt at least from the author's point of view—*that more money has been wasted, for want of just such knowledge as a River Commission might provide, than would have sufficed to pay the entire cost of it many times over.* Certainly, so far as training works in connection with bridges are concerned, in rivers of the class with which the author has chiefly concerned himself, most engineers responsible for such works would probably admit that whether they spent money unnecessarily as an insurance against their inevitable lack of scientific data, or that they were unduly economical, with either disaster, or heavy annual recurring expenditure in after-years, as the result. Thus looked on from the lowest or merely commercial standpoint, the establishment of such a Commission ought to be highly remunerative.'

The Government very slow to adopt Spring's advice

Unfortunately the sound advice given by Spring has not been acted on very quickly by the Governments. But Sir F Spring was not the only man who voiced this opinion. Mr Reakes, who was entrusted by the Bengal Government with the task of surveying the Nadia Rivers, was so puzzled by the problem of river changes in Bengal, that he made practically the same recommendations as Sir F Spring. But the Bengal Government has shown no intention of profiting by these advices. It is only the

Punjab Government which profited by the advice given by Spring, and has created, within the last 10 years, a well-equipped research laboratory, the staff of which contains, not only irrigation engineers, but also physicists, statisticians, mathematicians and people belonging to other branches of science, who can render sufficient help in tackling the problems of irrigation and of river control The Central Government maintains a River Physics Laboratory near Poona, where experiments on the models of the rivers have been carried on under the able guidance of Mr. Inglis for about 10 years, and many problems submitted by engineers from different parts of India have been tackled there. But considering the vast size of the country, the diversity of the problems in the different regions, the number of laboratories is extremely small and the equipment of those laboratories which have been constructed is not sufficient. Even in the Punjab, the work done is not considered sufficient Dr. Mackenzie-Taylor, Director of the Irrigation Research Laboratory of the Punjab, says·

'Though India is a country of mighty rivers, very little has been done here by way of experiments in the laboratories on river models Only in recent years have some experiments been conducted at the Hydro-dynamic Research Station at Khadakvasla near Poona and at the Punjab Irrigation Research Institute, Lahore'

The provinces of the lower Ganges valley which, more than any other provinces, require a thorough field study of their rivers, as well as investigations on river-models in laboratories prior to any work being undertaken, have hitherto shown complete indifference to the proposals of having hydraulic research laboratories. All the same, blundering projects have been pushed through, which have wasted crores of the taxpayers' money A small fragment of these sums, spent on the establishment and proper equipment of hydraulic research laboratories, would have been of immense benefit to the country

8 *Problems of the Lower Ganges Delta*

I will illustrate my case by special reference to Bihar and Bengal. I have already told you that the problems in these two provinces are entirely different from those of the semi-arid areas of the Punjab and the upper Ganges valley, yet in the past works have been pushed on in these provinces which ought never to have been undertaken. The main problem as you see here is not one of supply of water in the same way as to the thirsty areas of the Punjab or of the Western U P, but entirely different. These provinces have a copious rainfall, the peasantry here very seldom require water for irrigating their fields; the problem here is to get rid of the excess water as quickly as possible, prevent the rivers from changing their courses, minimize the effect of destructive floods, and prevent the formation of unhealthy marshes and swamps. This can be done only by a judicious control of the activities of the rivers or by river-training Unfortunately the engineers who were

entrusted with the planning of bridges and embankments for the protection of railways in these provinces, and also with the charge of irrigation, were not sufficiently familiar with the peculiar conditions of these provinces and used in the solution of their tasks their knowledge of irrigation obtained in other provinces. This has been mainly responsible for the large amount of wastage in irrigation which is marked by the department as unproductive But it has done worse things than that The people of Bengal have always clamoured that the railway embankment has ruined the Burdwan division. It changed the courses of rivers in this division and deprived the land of the fertilizing silt. The Burdwan division became thereby a victim to malaria which, between 1860 and 1870, carried off nearly half of her population

Central Bengal, a country of dead rivers

The same is true of Central Bengal but here the ravages are due to the change in the course of the river The Ganges used formerly to discharge its water through the western branches but now the mouths of these channels have been silted up and the main mass of water flows through the easternmost channel. This has made Central Bengal a land of dead rivers and swamps and a prey to malaria The problems of Bengal have been so very ably treated by Mr S. C Majumdar that it is useless for me to go into great detail By his careful survey and analysis he has also pointed out the way in which the rural conditions can be improved He has clearly shown that this can be done only by the undertaking of a large amount of engineering work aimed at controlling the rivers judiciously. But I submit that satisfactory results can be achieved only if the problem is studied very carefully before any work is undertaken The need here is for studying the rivers intimately We must take observations for a number of years regarding the flow of rivers, variation of the flow throughout the year, how they depend upon the precipitation in basins, how they deposit their burden of silt and what is the action of the silt on the fertility of the soil. We have to undertake fundamental experiments, for as Dr. N. K. Bose and Mr Lacey will tell you there are many fundamental problems in river physics which still await solution. They are still the subject of careful study by distinguished workers. It is necessary to have in each region a River Physics Laboratory where the fundamental problems will be handled by a number of expert pure scientists In addition there is need for a properly equipped field survey department which will survey the contour and geological formation, the carrying capacity of the river-beds and ultimately, whenever any constructional work is proposed, this should be studied by a laboratory model carefully. After all these studies are completed actual work should be undertaken.

9. *Cheap Electrical Power.*

Within the last fifty years, another use has been found for running water which is as important as irrigation and navigation, viz. generation of cheap electrical power out of the energy of running water This is a subject which is

just beginning in India, but its importance has not been properly realized. I wish therefore to dwell at some length on this point.

Analysis of Professions in India

Everybody knows that India is an agricultural country. According to the Census Report of 1931, 66% of the Indian population is engaged in agriculture, i e are peasants, i e they have to spend their life in raising food. Of the remaining 34%, only 11% are city-dwellers, i.e. engaged in industries and other professions The remaining 23% are either village artisans, merchants, landlords, or belong to other professions mainly dependent on a rural economy

India, a land of poverty-stricken peasants

Everyone will admit that the distribution of the population according to professions reveals a very unhealthy state of affairs. In no other country of the world, excepting such backward ones as China, is there such a large proportion of peasants And do these peasants enjoy a good living ? A few huts, mostly without doors or windows, a few mats and rags, a few half-starved animals, hunger, debt, and frequent disease,—this is all they have to enjoy!

Agricultural Improvement—no solution of the poverty problem

There is a widespread desire for improving the lot of peasants and to raise the general standard of living But how can this be achieved ? Not by an exodus of the townsmen to the villages as advocated by certain persons distracted by middle class unemployment, for that will merely increase the pressure on the overcongested rural area and multiply misery Greater efficiency in agricultural methods, which is certainly desirable, may give us more and cheaper food, and other necessities of life obtained from agriculture (like cotton), but it can never touch even the fringe of the poverty and unemployment problem For greater efficiency amounts to the fact that the same production in agriculture can be effected by half the present number At present, the proportion of food-gatherers is 66% They produce food materials and other products by the most primitive methods If improved scientific methods are adopted, larger amounts, more than sufficient for the whole nation, can be produced by 30% of the population This will render about 36% of the peasant population unemployed. This added to the already existing middle class unemployment will render matters worse

Industrialization the only solution of the poverty problem

If we analyse the widespread public sentiment for better living, what do we find ? Everybody of course wants his food supply to be insured, but this is the least part of his demands He wants to be better clothed and better housed, wants to get a better education for himself and his family, more rest from work, freedom from drudgery and greater enjoyment of life. Analysing this sentiment, we find that if these needs are to be satisfied, the quantity of industrial products has to be increased ten to twenty times its present level; all these works have to be organized, and a large proportion of the village population is to be diverted from the task of food-raising to industrial work. In fact, the only way to improve the villages is

by drafting more villagers to the cities, and by creating a larger number of cities based on industries

10 *India's fitness to be industrialized*

India has sufficient resources for efficient industrialization

But all countries, even if they want to have a better living, as is reached to-day by some European countries, cannot do so on account of their intrinsic poverty in natural resources The source of potential wealth to-day is not merely good agricultural land of all varieties, capable of yielding all kinds of food and other economic products, but also mines, capable of yielding minerals useful to man, and sources of power (coal, oil, peat and other fuel, water power) A recent writer in the *East Indian Review* analysing the conditions of the world, finds that only three countries in the world satisfy these conditions, viz, U S A, Soviet Russia, and India He traces much of the present political troubles of the world to poor resources possessed by many ambitious nations Italy, for example, has almost no coal or iron, and very little mineral resources Hence her desire to seize other undeveloped lands, otherwise she cannot reach the modern standard of better living Japan is almost in an identical condition, and is further handicapped in having poor agricultural land as the country is not suited for the production of any agricultural stuff other than rice and mulberry Cotton and oil-seeds cannot be grown on her soil Hence her desire to seize parts of China According to this author, China, even if she were not pestered by foreign aggressors, and could solve her own internal problems, can never attain the level of the U S A or the future Russia, because her mineral resources are poor Only India possesses all kinds of resources in abundance, she continues to be poor, only because these resources have not been developed and industrial work has not been properly planned and organized

How to organize production and distribution of commodities essential for civilized human life

The wealth of a people is neither a gift of the heavens, nor a gift of nature The people have to create wealth by organized labour The more the output of work by a country, the richer it is and the higher the standard of living reached Probably, most of our countrymen have no idea that the total work output by the average Indian is twenty times less than that of the average American and European In previous epochs of history, all the work used to be done by human power, or animal power But at the present time, most work is done by steam-engines, oil engines or electricity Let us compare quantitatively the work output per man in Norway and in India I am taking Norway because there all power is electrical and can be easily calculated

The League of Nations' Year-book tells us that the average Norwegian consumes 1,600 units of energy per capita in the year, which is mostly derived from the harnessing of her rivers and waterfalls

As we shall see presently, the man power and animal power probably does not contribute more than 80 units per year. Hence the total output of energy per capita in a civilized State is about 1,700 units. With less output, the standard of living would go down.

India produces 20 times less work per capita than European countries

Let us see the average output per Indian. The electrical energy per capita in this country is only 7. Steam and oil power will not amount to more than 10 Let us now calculate the work done by man and animal. A labourer working for eight hours daily produces only $\frac{6}{10}$ units and in a year of 300 working days he does not produce more than 180 units But only one-third of men and women are active. Hence the average output per year per capita is only 60 units. Taking the work done by animal power to be 10, the total output of work per capita per year is only 90 units This is nearly twenty times less than the work output per European, and about 6 to 8 times less than that of the Japanese.

To use figurative language. The average European has 20 slaves constantly working for him while the Indian has mostly to depend upon himself. The slaves which the European calls to his aid are provided from the exploitation of the power resources of his country. Such resources though they exist in India have not been developed and profitably utilized. This is the root cause of poverty in India.

Not only have the power resources not been developed, but the available power is extremely dear. This is one of the main causes of India's backwardness in industrialization.

Dearness of Power

How much India is handicapped in this respect may be gathered from the fact that the price of power in this country for the greater part of the country is four times that in England and Japan, except probably for steam power, which is not suited for many industries, and is not available in all parts of the country.

Thus the cheapest electrical power at Calcutta costs ¼ anna—·57*d.*, the average price of power is about 1*d* and at Allahabad—2 annas—2·2*d.*, in London electricity if bought in bulk can be had for ½*d* per unit.

High Price of Power

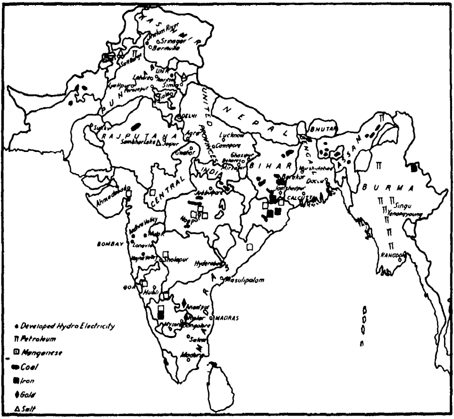
The price of petrol varies from Re.1-2 as to Re 1-10 as, while the price in England and Japan is about 6 annas. Most of the extra cost is due to customs duty and railway freight. The landing cost is only about 4 annas. On account of the great cost of petrol, Otto engines are very expensive to work in India.

It is on account of the high price of power that industrial enterprise has so far been confined to cities like Calcutta which are near coal mines, or Bombay which possesses, thanks to the enterprise of the Tatas, cheap hydroelectric power. Other areas cannot develop unless they are provided with cheap power.

11. *How to develop power resources*

India rich in Power Resources

But it may be asked, are there sufficient power resources in India? Like some other countries in the world, India may be intrinsically poor in power resources Let us consider this problem in detail The chief power resources are —Coal, water power, oil, shale, and other fuel (peat, wood, bagasse, power alcohol and vegetable oils).



MAP 6.
(From Coggin Brown's *Mineral Resources of India*)

I have before you a map of India (Map 6) showing the occurrence of coal deposits. You will see that these resources are present only in certain parts of Bengal, Bihar, Orissa and Assam, in other words in Eastern India. Other parts of India are extremely deficient in coal, or do not possess it at all. If India wants to be industrialized, it must develop its available water power. Let us see how much has been done in this connection.

The water power resources of India have not yet been adequately surveyed except in a few isolated regions. The work which was started

under Meares in 1919 was unfortunately stopped for some unknown reason According to this authority, the total resources amount to about 20 million kilowatts, but this may probably be a gross underestimate, as in the case of Soviet Russia.

Necessity for development of Water Power

The total power which has so far been developed amounts to about half a million kilowatts installed Of these, ·3 million kilowatts or about 60% is due to an Indian State (Mysore) and private (mostly Tata's) enterprise, and the rest is due to the enterprise of the Provincial Governments

These figures show that only 2·5% of India's hydroelectric power resources has been developed.

The efficiency of the undertakings which have so far been developed leaves much to be desired.

The earliest large project in India is the Sivasamudram Hydroelectric Works in Mysore which owed its genesis to the far-sighted vision of Dewan Seshadri Iyer of Mysore. It has developed nearly 50,000 kilowatts, and the cost of installation has been nearly Rs 500 per kilowatt installed. The three Tata projects near Bombay cost about Rs 500–600 per kilowatt installed, inclusive of transmission lines

Bad beginning in hydroelectric development

The upper reaches of the Indus and the Ganges valley offer unique opportunities for hydroelectric development and there is great need for such development if these areas are to be industrialized, as there exists neither coal nor petrol in sufficient quantity in these parts But the results obtained so far have been rather discouraging. The Mundi Scheme in the Punjab, which was launched under Government initiative against the almost unanimous opposition of the people's representatives, cost nearly Rs 3,000 per kilowatt installed , this holds the world's record for dearness, and is about 10 times dearer than the average cost of installation of plants of this size in Europe and America. The Western Ganges Hydroelectric Scheme which appears to have caught the imagination of a large majority of our countrymen cost Rs 1,200 per kilowatt installed This holds the second highest record for dearness, and yet such a project has been hailed as a great work by a section of our countrymen

But the reader may ask, what have rivers to do with electrification schemes ? As has been pointed out, electrical power in most parts of India can be obtained only from water power, hence it is obvious that before an expensive scheme is launched (and all hydroelectric schemes are expensive). extensive preliminary studies are to be made. These include a summary of the water power resources showing the variation of discharge of rivers, possibility of erecting storage reservoirs, finding out the best site, and further economic survey with a view to utilization of all the power developed Even when a site has been chosen, extensive laboratory experiments should be carried out with the aid of models on the proposed dams, weirs, reservoirs, etc. before any work is actually undertaken. If one goes critically into the history of

the unsuccessful works just mentioned, he will find that the root cause of failure was that schemes were launched by enthusiasts (in many cases by amateurs in hydroelectric engineering) without adequate surveys and preliminary experiments. In the Mundi Scheme, nearly 6 crores of rupees were wasted before it was discovered that the river from which power was to be tapped almost ran dry during the hot season. If a small part of this money was spent on adequate surveys, and preliminary laboratory researches, probably the Government would have received a handsome return on their investment, most part of which has now to be written off as unproductive.

Example of Soviet Russia

Let us contrast the procedure adopted in this country with that in Soviet Russia Before the Great War, Russia was no better than India She was mainly an agricultural land, 70% of the population were peasants, almost as poor and ragged as the present-day peasants in India. Industries were in a backward state, and power was undeveloped and considered a luxury. The total amount of electrical energy per capita was only 15 units which, in 1919, owing to the ravages of the War and the Revolution fell to about 5 units She was without knowledge of her power resources, without experts and technicians. It was during these dark days that Russia, under the influence of Lenin, started schemes for planned electrification for the whole country which was part of the larger scheme of complete industrialization Now within a short period of 16 years, Russia is producing nearly 300 units per capita. Her production of electricity in 1937 exceeded that of any other country in the world, excepting the U.S.A., and if she can complete all her schemes, she will soon overtake the U S A. Needless to add that thanks to this intense electrification, Russia has passed from an agricultural State to an industrial one, and now 70% of her population are reckoned as industrial workers She is on a fair way to the solution of the problems of poverty, disease and famine which perpetually haunted her peasant population of 70% before the Revolution

There is a great prejudice in this country as well as in Europe against everything Russian, but not being a politician I am not interested in their political theories or the execution of those theories What strikes me as a scientific man is the extraordinary use they have made of modern scientific knowledge in solving their problems of poverty and want, and the extremely judicious and businesslike fashion in which they proceeded with their schemes and co-ordinated the labours of economists and technicians. I have on my table a book written for the World Power Conference on the Electrification of Russia. We learn from this book that when the supreme council of the Soviets adopted Lenin's resolution for the electrification of the country, it was the U.S.S.R Academy of Sciences and not a committee of bureaucrats which was requested to give a plan Under the guidance of the Academician Prof. Krzhizhanovski the following plans were adopted · (1) Immediate establishment of a Power Research Institute for undertaking a survey of the existing

power resources, coal, peat, oil, shale, and above all of water power, in the U.S.S.R. (2) Establishment of an extensive scheme of hydrological survey—so far the U.S.S.R. possesses 5,200 hydrological stations of all classes, for surveying the discharge of rivers at different points, their variation throughout the year, etc. (3) Establishment of a number of River Physics Laboratories at Tashkent, Moscow, and Leningrad and other centres where researches with laboratory models of projected weirs, dams, embankments, canals are carried out before any work is actually undertaken (4) Establishment of a comprehensive scheme for training an army of technicians in Russia

The Russian Method of Attack

It goes without saying that the plan adopted by Russia is the correct one. A scheme is known by its fruits. Russia now instals every year power-stations of millions of kilowatts capacity instead of thousands. The energy produced is utilized by the properly planned industries, and in transport, and only a small percentage is utilized in agriculture. Thus within the last sixteen years, the nation has passed from a community of half-starved peasants to well-fed and well-clad industrial workers

12. *Conclusion*

Before I conclude, let me place before you a challenging statement from a very interesting book by Dr Vera Anstey. In her 'Economic Development of India' (1936) she says :—

> 'Here is a country of ancient civilization, with rich and varied resources, that has been in intimate contact with the most materially advanced countries of the West, but which is still essentially mediæval in outlook, and organization, and which is a byword throughout the world for the poverty of its people.'

Then she quotes Mr. M. L. Darling :

> 'The most interesting thing about India is that her soil is rich and her people are poor' and asks herself :

> 'Can India be called "Mediæval" when it is organized under a modern form of constitutional Government, possesses a great system of mechanical transportation, a unique system of irrigation, no less than seventeen modern Universities, and has several large-scale industries producing with the most up-to-date machines that have yet been invented ?'

The answer, however galling to our pride, must be that in point of poverty, ignorance and disease, India of today can only be classed with China and Abyssinia, countries which are still steeped in mediævalism, and have paid the price for continuing mediævalism.

If we desire to fight successfully the scourge of poverty and want from which 90% of our countrymen are suffering, if we wish to remodel our society

and renew the springs of our civilization and culture, and lay the foundations of a strong and progressive national life, we must make the fullest use of the power which a knowledge of Nature has given us We must rebuild our economic system by utilizing the resources of our land, harnessing the energy of our rivers, prospecting for the riches hidden under the bowels of the earth, reclaiming deserts and swamps, conquering the barriers of distance and, above all, we must mould anew the nature of man in both its individual and social aspects, so that a richer, more harmonious and happier race may people this great and ancient land of ours Towards the realization of this ideal, we must adopt ourselves to the new philosophy of life and train the coming generations for the service of the community in scientific studies and research

ON THE PROPAGATION OF ELECTROMAGNETIC WAVES THROUGH THE EARTH'S ATMOSPHERE (Paper 1)

By M. N SAHA, *D Sc* , *F R S* , R N. RAI, *M Sc* , *and* K. B MATHUR, *M Sc*

(*Read November 6, 1937*)

INTRODUCTION

The introduction to this paper has already been given in another with the same heading published in these *Proceedings* (Vol III, p 359, 1937) henceforth called paper 2. The present paper deals with the derivation of the equations given in §2, pp 363 and 364 of paper 2 There only a bare statement of the equations was given; here the exact procedure of their derivation is given The programme of these series of papers may be defined as the wave-treatment of the problem of propagation dealing with questions of polarization, reflection, oblique propagation, and absorption of the waves We first give a fuller description of the notation employed

NOTATION

The notation used in this field of investigation differs so widely from one author to another that the reading of papers by different authors is attended with a certain amount of difficulty It is desirable that a system of international notations be agreed upon In this paper, an attempt has been made to use a system of symbols which may be acceptable to the different schools of investigators We have, as far as possible, adhered to the symbols used by S K Mitra, which were mostly adopted from the writings of Appleton and his school. In some points we have found it necessary to deviate from Mitra's symbols An explanation of the system of symbols is therefore given at the beginning.

E	Electric Field Intensity with components	E_x, E_y, E_z
D	Electric Displacement Vector	D_x, D_y, D_z
H	Magnetic Field Vector	H_x, H_y, H_z
B	Magnetic Polarization.	
P	Polarization	P_x, P_y, P_z
h	Earth's magnetic field components	h_x, h_y, h_z.

(Mitra has used H for this quantity But it produces a certain amount of confusion with the magnetic field vector, hence we have used 'h' to denote the earth's field.)

p_h .. Larmor Frequency $\frac{eh}{mc}$.

p_x, p_y, p_z Components of Larmor Frequency.

p Pulsatance of the electromagnetic wave.

N .. Number of electrons, or ions per c.c. at any height Whenever necessary the subscript 'e' for electron, 'i' for ion is affixed to N. Thus N_e denotes number of electrons. But usually the suffix is not used.

$p_0^2 = \frac{4\pi Ne^2}{m}$ either for electrons or ions.

ν .. collisional frequency, i.e number of collisions made by an ion or electron in unit time.

$(\omega_x, \omega_y, \omega_z) = \frac{1}{p}(p_x, p_y, p_z)$, ω is the resultant value of $(\omega_x\ \omega_y\ \omega_z)$

$$= \frac{1}{p}(p_h) = \frac{eh}{mcp}$$

$$r = \frac{p_0^2}{p^2} = \frac{4\pi Ne^2}{mp^2}$$

$$\beta = 1 - \frac{i\nu}{p} = 1 - i\delta$$

q = Complex Refractive Index

$= \mu - i\chi$

§ 1

THE FUNDAMENTAL EQUATIONS.

The fundamental equations for the propagation of electromagnetic waves are —

$$\left.\begin{aligned} \text{Curl } H &= \frac{1}{c}\dot{D} \\ \text{Curl } E &= -\frac{1}{c}\dot{B} \\ \text{Div } D &= 4\pi\rho \\ \text{Div } B &= 0 \\ D = kE &= E + 4\pi P \end{aligned}\right\} \quad \ldots \quad \ldots \quad \ldots \quad (1\ 1)$$

For the present case, we take $\mu = 1$ so that

$$B = \mu H = H.$$

From equation (1 1) it can be deduced in the usual way that

$$\left.\begin{aligned}\nabla^2 H &= \frac{1}{c^2}\,\ddot{H}-\frac{4\pi}{c}\,\mathrm{Curl}\,\dot{P}\\ \text{and}\qquad \nabla^2 E &= \frac{1}{c^2}\,\ddot{E}+\frac{4\pi}{c^2}\,\ddot{P}-4\pi\,\mathrm{grad\,div}\,P\end{aligned}\right\} \quad . \quad . \quad (1\ 2)$$

We have now to express P in terms of E

Let us suppose that on account of the e m field of the radio wave the charged particles suffer the displacement ξ, η, ζ The equations of motion of the charged particles are given by

$$\left.\begin{aligned} m\ddot{\xi} &= eE_x-g\dot{\xi}+\frac{e}{c}\,(\dot{\eta}h_z-\dot{\zeta}h_y)+aP_x\\ m\ddot{\eta} &= eE_y-g\dot{\eta}+\frac{e}{c}\,(\dot{\zeta}\,h_x-\dot{\xi}h_z)+aP_y\\ m\ddot{\zeta} &= eE_z-g\dot{\zeta}+\frac{e}{c}\,(\dot{\xi}h_y-\dot{\eta}h_x)+aP_z\end{aligned}\right\} \quad .. \quad (1\ 3)$$

Here $-g(\dot{\xi}, \dot{\eta}, \dot{\zeta})$ represents the frictional force due to collisions

The third term. $\frac{e}{c}\,(v\times h)$ represents the deflecting force due to the earth's magnetic field

We have further $P = Ne\ (\xi, \eta, \zeta)$, where N is the number of electrically charged particles per unit volume

The last term in (1.3) represents the action of the polarization forces It is now usual to take $a = 0$

We shall replace (ξ, η, ζ) by $\frac{1}{Ne}\,(P_x, P_y, P_z)$ throughout (1 3), and let us further suppose that P is proportional to e^{ipt} Then the equations (1.3) reduce to

$$-\frac{mp^2}{Ne}\,P_x = eE_x-\frac{igp}{Ne}\,P_x+\frac{ip}{Nc}\,(P\times h)_x$$

and two other similar equations

The form of the equations can be much simplified if we make the following substitutions .—

$$\left.\begin{aligned}-\frac{mp^2}{Ne^2} &= -\frac{4\pi p^2}{p_0^2} = -\frac{4\pi}{r}\\ \frac{gp}{Ne^2} &= \frac{g}{m}\,\frac{p}{Ne^2/m} = \frac{4\pi}{r}\,\frac{\nu}{p}\\ \frac{ph}{eNc} &= \frac{eh}{mc}\,\frac{4\pi p}{4\pi Ne^2/m} = \frac{4\pi pp_h}{p_0^2} = \frac{4\pi\omega}{r}\end{aligned}\right\} \quad .. \quad . \quad (1\ 4)$$

Then the equations take the form

$$\left.\begin{aligned} \beta P_x+i\omega_z P_y-i\omega_y P_z &= -\frac{r}{4\pi} E_x \\ -i\omega_z P_x+\beta P_y+i\omega_x P_z &= -\frac{r}{4\pi} E_y \\ i\omega_y P_x-i\omega_x P_y+\beta P_z &= -\frac{r}{4\pi} E_z \end{aligned}\right\} \qquad (1.5)$$

These equations can be easily solved by the usual algebraic methods We can put

$$\left.\begin{aligned} \frac{P_x}{A} &= \Delta_{11}E_x+\Delta_{21}E_y+\Delta_{31}E_z \\ \frac{P_y}{A} &= \Delta_{12}E_x+\Delta_{22}E_y+\Delta_{32}E_z \\ \frac{P_z}{A} &= \Delta_{13}E_x+\Delta_{23}E_y+\Delta_{33}E_z \end{aligned}\right\} \qquad (1.6)$$

where $$A = \frac{r}{4\pi\beta}\,\frac{1}{\beta^2-\omega^2}.$$

Δ_{rs}, etc are the subdeterminants of the determinant formed by the coefficients of the quantities P_x, P_y, P_z in equations (1.5)

It can be easily shown that

$$\left.\begin{aligned} &\Delta_{11} = \omega_x^2-\beta^2 \quad &&\Delta_{21} = \omega_x\omega_y+i\beta\omega_z \quad &&\Delta_{12} = \omega_x\omega_y-i\beta\omega_z \\ &\Delta_{22} = \omega_y^2-\beta^2 &&\Delta_{32} = \omega_z\omega_y+i\beta\omega_x &&\Delta_{23} = \omega_z\omega_y-i\beta\omega_x \\ &\Delta_{33} = \omega_z^2-\beta^2 &&\Delta_{13} = \omega_x\omega_z+i\beta\omega_y &&\Delta_{31} = \omega_x\omega_z-i\beta\omega_y \end{aligned}\right\} \qquad (1.7)$$

These results will be utilized later

§ 2.

Propagation along the z-axis

We shall first consider the propagation of the rays along the z-axis Then the second set of equations (1 2) reduces to the three equations —

$$\left.\begin{aligned} \frac{d^2E_x}{dz^2}-\frac{1}{c^2}\frac{d^2E_x}{dt^2} &= \frac{4\pi}{c^2}\frac{d^2P_x}{dt^2} \\ \frac{d^2E_y}{dz^2}-\frac{1}{c^2}\frac{d^2E_y}{dt^2} &= \frac{4\pi}{c^2}\frac{d^2P_y}{dt^2} \\ \frac{d^2E_z}{dz^2}-\frac{1}{c^2}\frac{d^2E_z}{dt^2} &= \frac{4\pi}{c^2}\frac{d^2P_z}{dt^2}-4\pi\frac{d^2P_z}{dz^2} \end{aligned}\right\} \quad \ldots \quad \ldots \quad (2.1)$$

for the terms arising out of Grad Div P are now simplified as

$$\frac{\partial}{\partial x}(\mathrm{Div}\,P) = 0,\ \frac{\partial}{\partial y}(\mathrm{Div}\,P) = 0 \text{ and } \frac{\partial}{\partial z}(\mathrm{Div}\,P) = \frac{d^2P_z}{dz^2}$$

Further ∇^2 reduces to $\dfrac{d^2}{dz^2}$.

The third of equations (2.1) is

$$\left(\frac{d^2}{dz^2}-\frac{1}{c^2}\frac{d^2}{dt^2}\right)(E_z+4\pi P_z) = 0 \tag{2.2}$$

Now from the condition Div $D = 0$, we have

$$\frac{\partial}{\partial z}[E_z+4\pi P_z] = 0 \tag{2.3}$$

From (2.2) and (2.3), we have

$$D_z = E_z+4\pi P_z = 0 \tag{2.4}$$

As according to (1.6), P_z is a linear function of E_x, E_y, E_z, equation (2.4) enables us to express E_z in terms of E_x and E_y. We have

$$E_z+4\pi A\,(\Delta_{13}E_x+\Delta_{23}E_y+\Delta_{33}E_z) = 0$$

or

$$E_z = -\frac{\Delta_{13}E_x+\Delta_{23}E_y}{\left(\Delta_{33}+\dfrac{1}{4\pi A}\right)} \tag{2.5}$$

The equations (2.1) can now be put in the form :—

$$\left.\begin{aligned}\frac{d^2E_x}{dz^2} &= \frac{K_{11}}{c^2}\frac{d^2E_x}{dt^2}+\frac{K_{12}}{c^2}\frac{d^2E_y}{dt^2}\\ \frac{d^2E_y}{dz^2} &= \frac{K_{21}}{c^2}\frac{d^2E_x}{dt^2}+\frac{K_{22}}{c^2}\frac{d^2E_y}{dt^2}\end{aligned}\right\} \tag{2.6}$$

where

$$K_{11} = 1+4\pi A\left\{\Delta_{11}-\frac{\Delta_{13}\Delta_{31}}{\Delta_{33}+\dfrac{1}{4\pi A}}\right\}$$

$$K_{12} = 4\pi A\left\{\Delta_{21}-\frac{\Delta_{31}\Delta_{23}}{\Delta_{33}+\dfrac{1}{4\pi A}}\right\}$$

$$K_{21} = 4\pi A\left\{\Delta_{12}-\frac{\Delta_{32}\Delta_{13}}{\Delta_{33}+\dfrac{1}{4\pi A}}\right\}$$

$$K_{22} = 1+4\pi A\left\{\Delta_{22}-\frac{\Delta_{23}\Delta_{32}}{\Delta_{33}+\dfrac{1}{4\pi A}}\right\} \tag{2.7}$$

It is easily seen that

$$\left.\begin{aligned} D_x &= K_{11}E_x+K_{12}E_y \\ D_y &= K_{21}E_x+K_{22}E_y \end{aligned}\right\} \qquad . \qquad . \quad (2\ 8)$$

Equations for the propagation of the magnetic vector.

Instead of taking (1 2) we take the equation (1 1). We have then

$$\nabla^2 H = -\frac{1}{c}\,\text{curl}\,\dot{D} \qquad . \quad . \quad .. \quad . \quad (2.9)$$

$$\left(\text{for curl curl } H = -\nabla^2 H = \frac{1}{c}\,\text{curl } D\right)$$

These equations reduce to

$$\frac{d^2H_x}{dz^2} = \frac{1}{c}\frac{dD_y}{dz}, \quad \frac{d^2H_y}{dz^2} = -\frac{1}{c}\frac{d\dot{D}_x}{dz} \qquad .. \quad . \quad (2.10)$$

Now from (2 8) we have

$$\left.\begin{aligned} \dot{D}_x &= K_{11}\dot{E}_x+K_{12}E_y \\ D_y &= K_{21}E_x+K_{22}E_y \end{aligned}\right\} \qquad . \quad (2\ 11)$$

since the quantities K are not functions of time.

Further from the second equation of (1 1), we have

$$\text{curl } E = \left(-\frac{dE_y}{dz}, \frac{dE_x}{dz}, 0\right) = -\frac{1}{c}\left(\frac{dH_x}{dt}, \frac{dH_y}{dt}, 0\right) \qquad (2\ 12)$$

Applying these conditions to (2.10) and (2.11) we have, when the quantities K do not vary with z,

$$\left.\begin{aligned} \frac{d^2H_x}{dz^2} &= \frac{K_{22}}{c^2}\frac{d^2H_x}{dt^2} - \frac{K_{21}}{c^2}\frac{d^2H_y}{dt^2} \\ \frac{d^2H_y}{dz^2} &= -\frac{K_{12}}{c^2}\frac{d^2H_x}{dt^2} + \frac{K_{11}}{c^2}\frac{d^2H_y}{dt^2} \end{aligned}\right\} \qquad .. \quad (2\ 13)$$

Also from (2.12) and the first equation of (1 1) we have, utilizing (2.8),

$$\left.\begin{aligned} \frac{dE_x}{dz} &= -\frac{1}{c}\frac{dH_y}{dt}, \quad \frac{dE_y}{dz} = \frac{1}{c}\frac{dH_x}{dt} \\ \frac{dH_x}{dz} &= \frac{K_{21}}{c}\frac{dE_x}{dt} + \frac{K_{22}}{c}\frac{dE_y}{dt} \\ \frac{dH_y}{dz} &= -\frac{K_{11}}{c}\frac{dE_x}{dt} - \frac{K_{12}}{c}\frac{dE_y}{dt} \end{aligned}\right\} \qquad .. \quad .. \quad (2.14)$$

when $p_y = 0$, the last two reduces to

$$\left.\begin{aligned} \frac{dH_x}{dz} &= \frac{iL}{c}\frac{dE_x}{dt}+\frac{K_{22}}{c}\frac{dE_y}{dt} \\ \frac{dH_y}{dz} &= -\frac{K_{11}}{c}\frac{dE_x}{dt}+\frac{iL}{c}\frac{dE_y}{dt} \end{aligned}\right\} \quad \cdot\cdot \qquad (2\ 14')$$

where
$$L = -r(\beta-r)\omega_z/C'$$

We can now calculate the quantities K from the relations (2 7) First let us suppose that the collision frequency ν can be neglected. We have then

$$4\pi A = \frac{r}{1-\omega^2}$$

$$\Delta_{33}+\frac{1}{4\pi A} = \frac{\{(1-\omega^2)-r(1-\omega_z^2)\}}{r} = \frac{C}{r}$$

where
$$C = 1-\omega^2-r(1-\omega_z^2)$$

$$\left.\begin{aligned} \Delta_{11}-\frac{\Delta_{13}\Delta_{31}}{\Delta_{33}+\frac{1}{4\pi A}} &= \frac{(1-\omega^2)(r+\omega_x^2-1)}{C} \\ \Delta_{22}-\frac{\Delta_{23}\Delta_{32}}{\Delta_{33}+\frac{1}{4\pi A}} &= \frac{(1-\omega^2)(r+\omega_y^2-1)}{C} \\ \Delta_{21}-\frac{\Delta_{31}\Delta_{23}}{\Delta_{33}+\frac{1}{4\pi A}} &= \frac{(1-\omega^2)\{\omega_x\omega_y+i\omega_z(1-r)\}}{C} \\ \Delta_{12}-\frac{\Delta_{13}\Delta_{32}}{\Delta_{33}+\frac{1}{4\pi A}} &= \frac{(1-\omega^2)\{\omega_x\omega_y-i\omega_z(1-r)\}}{C} \end{aligned}\right\} \quad . \qquad (2\ 15)$$

From these expressions, we obtain the following values for the K's

$$\left.\begin{aligned} K_{11} &= 1+r\,\frac{\omega_x^2-1+r}{C} \\ K_{22} &= 1+r\,\frac{\omega_y^2-1+r}{C} \\ K_{12} &= r\,\frac{\omega_x\omega_y+i(1-r)\omega_z}{C} \\ K_{21} &= r\,\frac{\omega_x\omega_y-i(1-r)\omega_z}{C} \end{aligned}\right\} \quad . \qquad (2.16)$$

The expressions are considerably simplified if we put $p_y = \omega_y = 0$. This means that we are taking the magnetic meridian as our $(x-z)$-plane.

We have now

$$\left.\begin{aligned} K_{11} &= 1+r\,\frac{\omega_x^2-1+r}{C} = \frac{(1-r)(1-r-\omega^2)}{C} \\ K_{22} &= 1+r\,\frac{r-1}{C} \\ K_{12} &= -K_{21} = -iL \text{ where } L = -\frac{r(1-r)\omega_z}{C} \end{aligned}\right\} \quad \ldots \quad (2{\cdot}17)$$

When collisions are taken into account, it can be proved after some work that we have now the following relations.

$$\Delta_{33}+\frac{1}{4\pi A} = \frac{1}{r}\{\beta(\beta^2-\omega^2)-r(\beta^2-\omega_z^2)\} = \frac{C'}{r}$$

where

$$C' = \beta(\beta^2-\omega^2)-r(\beta^2-\omega_z^2) \qquad \ldots \quad \ldots \quad (2{\cdot}18)$$

$$\left.\begin{aligned} \Delta_{11}-\frac{\Delta_{13}\Delta_{31}}{\Delta_{33}+\dfrac{1}{4\pi A}} &= \frac{\beta(\beta^2-\omega^2)\{r\beta+\omega_x^2-\beta^2\}}{C'} \\ \Delta_{22}-\frac{\Delta_{23}\Delta_{32}}{\Delta_{33}+\dfrac{1}{4\pi A}} &= \frac{\beta(\beta^2-\omega^2)(r\beta+\omega_y^2-\beta^2)}{C'} \\ \Delta_{21}-\frac{\Delta_{31}\Delta_{23}}{\Delta_{33}+\dfrac{1}{4\pi A}} &= \frac{\beta(\beta^2-\omega^2)\{\omega_x\omega_y+i\omega_z(\beta-r)\}}{C'} \\ \Delta_{12}-\frac{\Delta_{13}\Delta_{32}}{\Delta_{33}+\dfrac{1}{4\pi A}} &= \frac{\beta(\beta^2-\omega^2)\{\omega_x\omega_y-i\omega_z(\beta-r)\}}{C'} \end{aligned}\right\} \quad \ldots \quad (2{\cdot}19)$$

It is easy to see that the relations (2.15) are deducible from (2 19) when collisions are neglected, i.e $\beta = 1$.

We can now write out values of K's from the above relations. We have

$$\left.\begin{aligned} K_{11} &= 1-r\,\frac{\beta^2-r\beta-\omega_x^2}{C'} \\ K_{22} &= 1-r\,\frac{\beta^2-r\beta-\omega_y^2}{C'} \\ K_{12} &= \frac{r\{\omega_x\omega_y+i\omega_z(\beta-r)\}}{C'} \\ K_{21} &= \frac{r\{\omega_x\omega_y-i\omega_z(\beta-r)\}}{C'} \end{aligned}\right\} \quad \ldots \quad \ldots \quad (2.20)$$

Considerable simplification is introduced by putting $p_y = \omega_y = 0$ We have now

$$\left.\begin{aligned} K_{11} &= 1 - r\frac{\beta^2 - r\beta - \omega_x^2}{C'} = \frac{(r-\beta)(\omega^2 + r\beta - \beta^2)}{C'} \\ K_{22} &= 1 - r\frac{\beta^2 - r\beta}{C'} \\ -K_{12} &= K_{21} = iL, \\ \text{where } L &= -r(\beta - r)\omega_z/C' \end{aligned}\right\} \tag{2 21}$$

When $\beta = 1$ (no collision), these expressions reduce to (2 17)

§3 Solution of the Fundamental Equations

The rigorous solution of the fundamental equations presents great difficulty, since the quantity $p_0^2 = \dfrac{4\pi Ne^2}{m}$ is not a constant, but varies with height Let us first treat p_0^2 as a constant, and see what result is obtained

Let us put

$$(E_x, E_y, H_x, H_y) = (A_1, B_1, C_1, D_1)\, e^{i\phi} \tag{3.1}$$

where $\phi = p\left(t \mp \dfrac{\mu z}{c}\right)$, the minus sign holds for the outgoing wave, the plus sign for the reflected wave 'μ' is the refractive index, which we have to find out When we substitute (3 1) in (2 14) for the outgoing wave, we have the following relation amongst the constants A_1, B_1, C_1, D_1

$$\left.\begin{aligned} \mu A_1 &= D_1, \quad \mu B_1 = -C_1 \\ \mu C_1 &= -iLA_1 - K_{22}B_1, \quad \mu D_1 = K_{11}A_1 - iLB_1 \end{aligned}\right\} \tag{3 2}$$

From these equations, or directly from (2 14), we obtain

$$\left.\begin{aligned} (\mu^2 - K_{11})A_1 + iLB_1 &= 0 \\ -iLA_1 + (\mu^2 - K_{22})B_1 &= 0 \end{aligned}\right\} \tag{3 3}$$

or for the magnetic vectors

$$\left.\begin{aligned} (\mu^2 - K_{11})D_1 + iLC_1 &= 0 \\ -iLD_1 + (\mu^2 - K_{22})C_1 &= 0 \end{aligned}\right\} \tag{3.3'}$$

i e. μ^2 is given by the roots of the quadratic equation

$$(\mu^2 - K_{11})(\mu^2 - K_{22}) - L^2 = 0 \tag{3 4}$$

Let us put

$$\frac{K_{11} - K_{22}}{2L} = f$$

Then it can be easily shown after a little work that the two values of μ are given by

$$\left.\begin{aligned} \mu_1^2 &= K_{11} - Lf\left(1 - \sqrt{1 + 1/f^2}\right) = K_{11} - L\rho_1 \\ \mu_2^2 &= K_{11} - Lf\left(1 + \sqrt{1 + 1/f^2}\right) = K_{11} - L\rho_2 \end{aligned}\right\} \tag{3 5}$$

where

$$\rho_1 = f(1-\sqrt{1+1/f^2}), \quad \rho_2 = f(1+\sqrt{1+1/f^2}) \qquad (3\ 6)$$

ρ_1 and ρ_2 are the roots of the equation,

$$\rho^2 - \frac{K_{11}-K_{22}}{L}\rho - 1 = 0$$

From equations (3.3) and (3.5) we have

$$\frac{B_1}{A_1} = \frac{\mu^2 - K_{11}}{-iL} = -i\rho$$

or $B_1 = -i\rho A_1$, $C_1 = i\rho\mu A_1$, $D_1 = \mu A_1$

Hence we have from (3.1),

$$\left.\begin{aligned} E_x &= A_1 \cos\phi, \quad E_y = A_1\rho \sin\phi \\ H_x &= -\mu A_1 \rho \sin\phi, \quad H_y = \mu A_1 \cos\phi \end{aligned}\right\} \qquad (3\ 7)$$

These equations show that the two waves are elliptically polarized. We have

$$\left.\begin{aligned} E_x^2 + \frac{E_y^2}{\rho^2} &= A_1^2 \\ \frac{H_x^2}{\rho^2} + H_y^2 &= \mu^2 A_1^2 \end{aligned}\right\} \qquad (3\ 8)$$

The ratio of the axes of the ellipses are—

(*a*) for the electric vector x-axis . y-axis $= 1\ \rho$

(*b*) for the magnetic vector x-axis y-axis $= \rho\ .\ 1$.

The sense of rotation is given by equations (3 7) and the sign of ρ can be taken only after we have discussed the values of ρ_1 and ρ_2

Let us now find out the special characteristics of the two waves. It is necessary now that the signs be properly taken.

In the northern hemisphere, the north-seeking (positive) magnetic pole points downwards as shown in the figure. Let 'h' denote the absolute value of the magnetic field. Then if 'δ' be the dip-angle, we have

$$h_x = h\cos\delta, \quad h_z = -h\sin\delta.$$

Now $\dfrac{eh}{mcp} = \omega$ is itself negative, because 'e' is negative. We have therefore

$$\omega_x = -\omega\cos\delta, \quad \omega_z = \omega\sin\delta$$

where ω is the quantity $\left|\dfrac{eh}{mcp}\right|$.

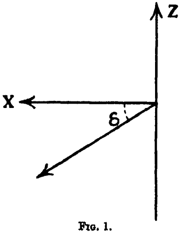


FIG. 1.

In the southern hemisphere, the dip is upwards for the positive pole, hence we have simply to substitute $(-\delta)$ for δ in the above expression. With the notation used here it is easy to see that

$$\left.\begin{aligned} K_{11} &= \frac{(1-r)(1-r-\omega^2)}{C} = \frac{t(t+\omega^2)}{C}, \quad t = r-1 \\ L &= -\frac{r(1-r)\,\omega_z}{C} = \frac{t(1+t)\,\omega \sin\delta}{C} \\ f &= \frac{K_{11}-K_{22}}{2L} = \frac{\omega\cos^2\delta}{2t\sin\delta} \end{aligned}\right\} \tag{3.9}$$

We have now

$$\left.\begin{aligned} \mu_1^2 &= K_{11}-L\rho_1 = K_{11}-Lf\left(1-\sqrt{1+1/f^2}\right) \\ C\mu_1^2 &= t(t+\omega^2)-\frac{(1+t)}{2}\omega^2\cos^2\delta\left\{1-\sqrt{1+\frac{4t^2\sin^2\delta}{\omega^2\cos^4\delta}}\right\} \\ C\mu_2^2 &= t(t+\omega^2)-\frac{(1+t)}{2}\omega^2\cos^2\delta\left\{1+\sqrt{1+\frac{4t^2}{\omega^2}\frac{\sin^2\delta}{\cos^4\delta}}\right\} \end{aligned}\right\} \tag{3.10}$$

The expressions for μ_1^2, μ_2^2 are independent of the sign of 'δ' and hence hold for both hemispheres We further observe that

(a) $\mu_1^2 = 0$ when $t = 0$

Hence μ_1 represents the conventional ordinary wave, for $t = 0$ is equivalent to the condition

$$p_0^2 = p^2 \tag{3.11}$$

(b) To prove that $\mu_2^2 = 0$ when $t^2 = \omega^2$

In this case, we have

$$\sqrt{1+\frac{4t^2\sin^2\delta}{\omega^2\cos^4\delta}} = 1+\frac{2\sin^2\delta}{\cos^2\delta}$$

$$\therefore\quad 1+\sqrt{1+1/f^2} = 2\sec^2\delta, \text{ and}$$

$$\begin{aligned} C\mu_2^2 &= t(t+\omega^2)-(1+t)\omega^2 \\ &= t^2-\omega^2 \\ &= 0 \end{aligned}$$

This condition gives us that $\mu_2 = 0$ when $t = \pm\omega$

or

$$\frac{p_0^2}{p^2} = 1\pm\frac{p_h}{p} \text{ or } p_0^2 = p^2\pm pp_h \tag{3.12}$$

These are the conditions of reflection for the extraordinary wave μ_2 therefore represents the extraordinary wave

Limiting cases —

(1) When $\delta = 0$ (Magnetic Equator—Transverse Case).

We can show from (3.10) that

$$\mu_1^2 = -t = 1-r, \; \mu_2^2 = -\frac{t^2-\omega^2}{t+\omega^2}$$

The $(\mu_1^2, 1-r)$ curve is the straight line representing the ordinary wave in

Mitra's Report (1935). The μ_2^2, r curve resolves into two curves on either side of the $(\mu_1^2, 1-r)$ line.

(2) When $\delta = \pm\frac{\pi}{2}$ (Magnetic Poles—Longitudinal case).

Now $\cos\delta = 0$, $\sin\delta = \pm 1$, and we easily see from (3.10) that

$$\mu_1^2 = \frac{t+\omega}{\omega-1}, \qquad \mu_2^2 = \frac{\omega-t}{1+\omega}$$

$$= \frac{1-r-\omega}{1-\omega} \qquad = \frac{\omega+1-r}{\omega+1}$$

$$= 1-\frac{r}{1-\omega} \qquad = 1-\frac{r}{1+\omega}$$

So the (μ_1^2, r) (μ_2^2, r) curves reduce to straight lines, which are reproduced in Mitra's Report, p 142

§ 4 POLARIZATION

As mentioned in § 3, the polarization factors are given by

$$\rho_1 = f[1-\sqrt{1+1/f^2}], \quad \rho_2 = f[1+\sqrt{1+1/f^2}] \quad \ldots \quad (4.1)$$

since $f = \dfrac{\omega^2\cos^2\delta}{2t\sin\delta}$ and $t = r-1$, $r = \dfrac{p_0^2}{p^2}$, f varies with the height of the point at which the wave is being considered, t varies from -1 at the ground to zero at $r = 1$ We need consider only the polarization of the ground wave. We have then

$$t = -1$$

$$f = -\frac{\omega\cos^2\delta}{2\sin\delta} \quad \ldots \quad \ldots \quad (4\ 2)$$

For the o-wave.

(a) Northern hemisphere

$$\rho_1 = -\frac{\omega\cos^2\delta}{2\sin\delta}\left[1-\sqrt{1+\frac{4\sin^2\delta}{\omega^2\cos^4\delta}}\right] \quad \ldots \quad (4\ 3)$$

Southern hemisphere, now ' δ ' must be changed to ' $-\delta$ ', we have then

$$\rho_1 = \frac{\omega\cos^2\delta}{2\sin\delta}\left[1-\sqrt{1+\frac{4\sin^2\delta}{\omega^2\cos^4\delta}}\right] \quad \ldots \quad \ldots \quad (4\ 4)$$

For the x-wave

(b) Northern hemisphere

$$\rho_2 = -\frac{\omega\cos^2\delta}{2\sin\delta}\left[1+\sqrt{1+\frac{4\sin^2\delta}{\omega^2\cos^4\delta}}\right] \quad \ldots \quad \ldots \quad (4\ 5)$$

Southern hemisphere

$$\rho_2 = \frac{\omega \cos^2 \delta}{2 \sin \delta}\left[1+\sqrt{1+\frac{4 \sin^2 \delta}{\omega^2 \cos^4 \delta}}\right] \tag{4.6}$$

In the table given below, we have calculated values of ρ_1, ρ_2 for a number of selected stations, for $\lambda = 100$ meters They are also given under fig 2

TABLE I

Place	δ	h	$r=\frac{eh}{mcp}$	$f = \frac{r \cos^2 \delta}{2 \sin \delta}$	Ordinary ρ_1	Extra-ordinary ρ_2	Remarks
N Pole	90°				1	−1	
Lerwick	72° 42′	4884	4509	0208	9794	−1 0210	
Slough	66° 54′	4702	4419	− 0370	9633	−1 0373	
Allahabad	46°	5182	487	− 1653	8487	−1 1793	
Bombay	25° 30′	4135	3710	− 3613	7017	1 4213	
Huancayo	2° 3′	2963	2693	−3 757	129	−7 643	
North of Equator	0			$-\infty$	0	$-\infty$	
South of Equator	0			$+\infty$	0	$+\infty$	
La Quiaca	−12° 21′	2684	2523	5631	− 5849	1 711	
Pilar	−25° 55′	2732	2576	·2387	− 7896	1·267	
Batavia	−32° 26′	·4369	4121	2752	− 7619	1 312	
Watheroo ..	−64° 19′	·2757	259	0271	− 9732	1 0274	
Melbourne ..		.	.		−·9569	1 0451	
S. Pole ..	−90°	..			−1	1	

Experimental Confirmation

These results have been experimentally confirmed Berkner states that at Huancayo: The ordinary ray is polarized with its electric vector along the magnetic north-south. Table (1) shows that

$$E_x\text{-axis} \,.\, E_y\text{-axis} = 1 \,.\, \cdot 129$$

i.e. the electric vector is mainly along the x-axis, i e. magnetic north-south

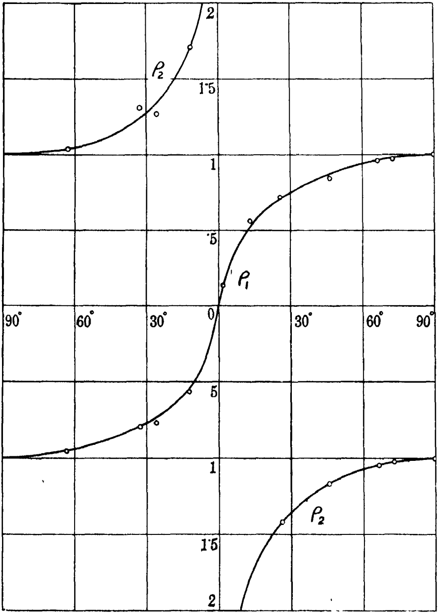


Fig. 2.

The extraordinary ray is polarized with its electric vector along the magnetic east-west Table (1) shows that

$$E_x\text{-axis} \;\; E_y\text{-axis} = 1 \;\; 7{\cdot}643$$

The variation of polarization for the *o*- and *x*-waves with latitude are shown in fig 2.

Conclusion

It is shown that if the complex refractive index be regarded as constant we get the same conditions for reflection and polarization of the radio-waves for vertical propagation as was obtained by Appleton But the refractive indices vary with height, hence the treatment given here should be replaced by a wave-treatment A simple case of wave-treatment has already been published in paper 2

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JOULE-THOMSON EFFECT AND ADIABATIC CHANGE IN DEGENERATE GAS [1]

By D S KOTHARI, *Ph.D*, *University of Delhi*

(*Read November* 6, 1937)

SUMMARY

An expression for the Joule-Thomson effect in a degenerate gas is derived A degenerate gas is heated after a Joule-Thomson expansion, the rise in temperature for a given fall in pressure being greater the greater the degree of degeneracy of the gas The case of adiabatic change is also discussed for comparison. An adiabatic expansion lowers the temperature, but the degree of degeneracy (and also the degree of non-degeneracy in the case of a non-degenerate gas) remains constant during an adiabatic change

INTRODUCTION

During recent years there have been numerous physical as well as astrophysical applications of the Fermi-Dirac statistics The researches beginning with Fowler (1) and later developed extensively by others, and particularly by Milne whose work has been of far-reaching importance, have established the fact that the essential features of the internal constitution of the white dwarf stars—stars characterized by a comparatively small luminosity, high effective temperature and an abnormally large mean density of the order of a million times that of water—can be explained by an application of the theory of degenerate electron gas—degenerate in the sense of Fermi-Dirac statistics Kothari and Majumdar (2) have recently worked out the degree of ionization in degenerate matter in terms of its density or pressure, and have shown that the usual theory of the white dwarf stars, when incorporated with the theory of ionization, becomes applicable to the planets as well, and leads to several interesting conclusions. The most important perhaps is the prediction that there exists a maximum radius for a *cold* [2] body. The maximum value depends to a certain extent on the chemical composition of the material, but as regards

[1] In a letter to me Professor Arthur Holmes, Professor of Geology, University of Durham (England) suggested the desirability of investigating temperature changes occurring in degenerate matter undergoing convection as it may have possible geological applications, and I desire to acknowledge that this note owes its origin to the stimulating correspondence with Professor Holmes.

[2] The word *cold* is used here in a technical sense The planets and white dwarf stars will be referred to as *cold bodies*. In general, matter will be referred to as cold when any free-electrons present constitute a degenerate gas in the sense of Fermi-Dirac statistics

the order of magnitude it is of the order of the radius of Jupiter, the largest planet in our solar system. Thus we see that degenerate matter forms an important constituent of stellar bodies and it is worth while therefore to study its various properties [1] In the present paper we shall deal with the Joule-Thomson effect and adiabatic change. This will have a possible application when dealing with temperature changes due to convection currents occurring in degenerate matter inside stellar and planetary interiors. However, we shall not be concerned with these applications in the present note.

In section I, we shall derive the expression for Joule-Thomson effect. It will be seen that a degenerate gas is heated (and not cooled) when it suffers Joule-Thomson expansion, the rise in temperature for unit fall in pressure is greater the greater the degree of degeneracy [2] of the gas After the Joule-Thomson expansion, because of the lowering of pressure (i e. electron concentration) and the rise in temperature, the degree of degeneracy is lower than originally. A degenerate gas, if it undergoes continuous Joule-Thomson expansion, will experience a rise of temperature at a gradually diminishing rate and will ultimately become non-degenerate, and, then, as its behaviour approximates to that of classical perfect gas, any further Joule-Thomson expansion will produce (practically) no more rise in temperature

In section II we deal with the case of adiabatic change An adiabatic expansion always lowers the temperature A degenerate gas undergoing adiabatic change (expansion or contraction) remains degenerate, the degree of degeneracy remaining constant during the change. Similarly a non-degenerate gas will remain non-degenerate (the degree of non-degeneracy remaining the same)

I. When a gas undergoes Joule-Thomson effect (also called throttling process)

$$d(E+pV) = 0 \quad . \quad .. \tag{1}$$

where E is the internal energy and V the volume, both for an assembly of N particles (N being the Avogadro number), and p the pressure of the assembly. Using the well-known thermodynamic relations

$$dQ = dE+pdV = C_p dt + l'dp \quad . \tag{2}$$ [3]

---

[1] According to some researches of Professor Milne all the stars (and not only the white dwarfs) possibly contain degenerate cores

[2] The degree of degeneracy is measured by the value of the degeneracy-discriminant A_0,

$$A_0 = \frac{nh^3}{2(2\pi mkT)^{3/2}},$$

where n is the free electron concentration, T the temperature, m the electron mass, and k and h denote Boltzman's and Planck's constant respectively (In this paper we neglect the effect of relativity mechanics. The expression for A_0 given above refers to the non-relativistic case.)

[3] Though hardly necessary, it may be permissible to make the following remarks about dQ in equation (2). dQ is defined as the heat flowing into the system when its

$$l' = -T\left(\frac{dv}{dT}\right)_p , \qquad \ldots \quad \ldots \quad \ldots \quad (3)$$

we obtain the standard expression for Joule-Thomson effect

$$\Delta T = \frac{T\left(\frac{dV}{dT}\right)_p - V}{C_p}\,\Delta p, \qquad . \qquad (4)$$

where ΔT represents the fall in temperature or cooling for a fall in pressure Δp C_p is the specific heat (per Avogadro number N) at constant pressure

In the case of degenerate gas the internal energy to a first approximation is given by the well-known expression (3)

$$E = \frac{3}{10}\frac{h^2}{m}\left(\frac{3n}{8\pi}\right)^{2/3} N\left[1+\frac{5}{12}\left(\frac{2\pi mkT}{h^2}\right)^2\left(\frac{8\pi}{3n}\right)^{4/3}\right]$$

$$= \frac{3}{5}\epsilon^* N\left[1+\frac{5}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}\right] \qquad (5)$$

where A_0 is called the degeneracy-discriminant (for degeneracy $A_0 >> 1$)

$$A_0 = \frac{nh^3}{2(2\pi mkT)^{3/2}} . \qquad \ldots \qquad (6)$$

and ϵ^* is the maximum energy of the Fermi-Dirac distribution, i.e. ϵ^* is the maximum kinetic energy possessed by any electron in an assembly of electron-concentration n and at absolute zero of temperature,

$$\epsilon^* = \frac{h^2}{2m}\left(\frac{3n}{8\pi}\right)^{2/3} \qquad . \qquad (7)$$

We note that

$$\left(\frac{3A_0}{4\pi}\right) = \left(\frac{\epsilon^*}{\pi kT}\right)^{3/2} \qquad (8)$$

Let us now determine C_v and C_p, the specific heats (per Avogadro number of free electrons) at constant volume and constant pressure respectively

We have from (5)

$$C_v = \left(\frac{dE}{dT}\right)_v = \frac{\pi^2 mk^2}{h^2}\left(\frac{8\pi}{3n}\right)^{2/3} NT = \frac{\pi^2}{2} R\,\frac{kT}{\epsilon^*} = \frac{\pi}{2} R\left(\frac{4\pi}{3A_0}\right)^{2/3} \qquad (9)$$

where $R = kN$ is the gas-constant

---

internal energy increases by dE and the external work done is pdv, p being the pressure of the system. But it is only during a reversible process that the external work equals pdv, in a non-reversible process it will be smaller. Therefore dQ does not represent the observed supply of heat, i e *heat actually supplied* except when the process is reversible. In a gas undergoing Joule-Thomson effect no heat is allowed to flow in or out, but that does not mean dQ is zero, for Joule-Thomson effect is non-reversible and so dQ cannot represent the observed heat supply which, however, is zero.

To determine C_p we can make use of the thermodynamic relation

$$C_p - C_v = T\left(\frac{dp}{dT}\right)_v \left(\frac{dV}{dT}\right)_p \quad \ldots \quad \ldots \quad (10)$$

Noting that[1]

$$p = \frac{2}{3}\frac{E}{V} \quad \ldots \quad \ldots \quad (11)$$

We at once obtain

$$\left(\frac{dp}{dT}\right)_v = \frac{2}{3}\frac{\pi^2 mk^2}{h^2}\left(\frac{8\pi}{3n}\right)^{2/3} nT = \frac{\pi kn}{3}\left(\frac{4\pi}{3A_0}\right)^{2/3} \quad \ldots \quad (12)$$

$$-V\left(\frac{dp}{dV}\right)_T = \frac{1}{3}\frac{h^2}{m}\left(\frac{3n}{8\pi}\right)^{2/3} n\left[1+\frac{1}{12}\left(\frac{2\pi mkT}{h^2}\right)^2\left(\frac{8\pi}{3n}\right)^{4/3}\right]$$

$$= \frac{2}{3}\epsilon^* n\left[1+\frac{1}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}\right] \quad \ldots \quad (13)$$

$$\left(\frac{dV}{dT}\right)_p = -\left(\frac{dp}{dT}\right)_v \Big/ \left(\frac{dp}{dV}\right)_T = \frac{V\frac{\pi}{2}\frac{k}{\epsilon^*}\left(\frac{4\pi}{3A_0}\right)^{2/3}}{1+\frac{1}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}} = \frac{V}{2T}\frac{\left(\frac{4\pi}{3A_0}\right)^{4/3}}{1+\frac{1}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}} \quad (14)$$

Substituting the above results in (10) we have

$$C_p - C_v = \frac{\frac{\pi}{6}\left(\frac{4\pi}{3A_0}\right)^2 R}{1+\frac{1}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}} \quad \ldots \quad \ldots \quad (15)$$

Substituting for C_v from (9) we get

$$C_p = \frac{\pi}{2}R\left(\frac{4\pi}{3A_0}\right)^{2/3}\left[\frac{1+\frac{5}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}}{1+\frac{1}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}}\right] \quad . \quad (16)$$

$$\doteq \frac{\pi}{2}R\left(\frac{4\pi}{3A_0}\right)^{2/3}\left[1+\frac{1}{3}\left(\frac{4\pi}{3A_0}\right)^{4/3}\right] \quad \ldots \quad (17)$$

Since for a degenerate gas $A_0 >> 1$, we notice that C_p differs very little from C_v, and this difference becomes smaller as the degree of degeneracy increases

[1] This is so in the *non-relativistic* case with which, as already mentioned, we are concerned in this paper In the *relativistic* case $p = \frac{1}{3}\frac{E}{V}$.

We have now to substitute the expressions for C_p and $\left(\frac{dV}{dT}\right)_p$ given by (16) and (14) respectively in (4) We obtain after a little reduction

$$\Delta T = -\frac{2}{\pi k n}\left(\frac{3A_0}{4\pi}\right)^{2/3}\left[\frac{1-\frac{5}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}}{1+\frac{5}{12}\left(\frac{4\pi}{3A_0}\right)^{4/3}}\right]\Delta p \tag{18}$$

$$\doteq -\frac{2}{\pi k n}\left(\frac{3A_0}{4\pi}\right)^{2/3}\Delta p = -\frac{2}{\pi^2 k n}\left(\frac{\epsilon^*}{kT}\right)\Delta p \tag{19}$$

$$= -\frac{3}{8\pi^3}\left(\frac{4\pi}{15}\frac{2h^2}{m}\right)^{1/5}\frac{h^2}{mk^2}\frac{1}{Tp^{1/5}}$$

where n is the number of free-electrons per unit volume

II We now consider an adiabatic process During an adiabatic change entropy remains constant The entropy of a degenerate gas is given by

$$S = R\pi^2\frac{kTm}{h^2}\left(\frac{8\pi}{3n}\right)^{2/3}, \tag{20}$$

and hence during an adiabatic process $\frac{n^{2/3}}{T}$ remains constant This ensures the constancy of the degeneracy-discriminant A_0, for

$$A_0 = \frac{nh^3}{2(2\pi mkT)^{3/2}} \tag{21}$$

The pressure of a degenerate gas is given by

$$p = \frac{8\pi}{15}\frac{h^2}{m}\left(\frac{3n}{8\pi}\right)^{5/3} \tag{22}$$

and, therefore, for an adiabatic process

$$\frac{p}{T^{5/2}} = \text{constant} \tag{23}$$

Further, as

$$p = \frac{2}{3}\frac{E}{V},$$

and since for adiabatic change

$$TdS = dE + pdV = 0, \tag{24}$$

it follows that $pV^{5/3}$ remains constant.

It is somewhat significant to note that the above relations representing adiabatic change in a degenerate gas are just the same as those governing adiabatic process for non-degenerate (i e. *classical* perfect) gas.

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JOULE-THOMSON EXPANSION OF A NON-DEGENERATE GAS

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(Communicated by Prof M N Saha, F R S)

(*Read November 6, 1937*)

Various properties of degenerate and non-degenerate matter have been investigated in recent years and these results have found numerous applications in various physical (1) and astrophysical (2) problems Kothari (3) has calculated the Joule-Thomson effect and adiabatic change in degenerate gas (degenerate in the sense of Fermi-Dirac statistics) and finds that the Joule-Thomson expansion of degenerate gas leads to heating It will be interesting to investigate this effect in non-degenerate gas and compare it with the effect calculated for a degenerate gas This is done in the present paper

According to classical thermodynamics the Joule-Thomson effect is given by the relation

$$\left(\frac{\partial T}{\partial p}\right)_H = -\frac{T\left(\frac{\partial V}{\partial T}\right)_p - V}{C_p}, \tag{1}$$

where $\left(\frac{\partial T}{\partial p}\right)_H$ denotes the Joule-Thomson effect and C_p the specific heat of the gas per N molecules (N = Avogadro number) We have to calculate the right-hand side in equation (1) for a non-degenerate gas

The usual expressions for the energy E and pressure p of a non-degenerate non-relativistic gas are the following [1] —

$$E = \frac{3}{2}NkT\left[1+\frac{\beta}{2^{5/2}f}+\qquad\right] \quad .. \tag{2}$$

$$p = nkT\left[1+\frac{\beta}{2^{5/2}f}+\text{terms in higher powers of }\frac{1}{f}\right] \tag{3}$$

where $\quad n = \frac{N}{V}, \quad \frac{1}{f} = \frac{nh^3}{g(2\pi mkT)^{3/2}}$

$\beta = +1$ for gas obeying Fermi-Dirac statistics

$\beta = -1$,, ,, ,, Bose-Einstein ,,

[1] See Saha and Srivastava, *A Treatise on Heat*, (2nd ed), p. 723

 [Published April 7th, 1938.

We shall neglect quantities containing squares and higher powers of $\frac{}{f}$ since in this case $f \gg 1$. Thus to a first approximation we have

$$C_V = \left(\frac{\partial E}{\partial T}\right)_V = \frac{3}{2}Nk - \frac{1}{2}\cdot\frac{3}{2}\frac{Nk\beta}{2^{5/2}}\cdot\frac{nh^3}{g(2\pi mk)^{3/2}T^{3/2}}$$

$$= \frac{3}{2}Nk\left[1 - \frac{1}{2}\cdot\frac{\beta}{2^{5/2}f}\right] \quad \ldots \quad (4)$$

To find C_p we use the well-known thermodynamical relation

$$C_p - C_V = T\left(\frac{\partial p}{\partial T}\right)_V \left(\frac{\partial V}{\partial T}\right)_p \quad (5)$$

Using (3) we get

$$\left(\frac{\partial p}{\partial T}\right)_V = nk\left[1 - \frac{1}{2}\,\frac{\beta}{2^{5/2}f}\right] \quad \ldots \quad (6)$$

$$\left(\frac{\partial p}{\partial V}\right)_T = \frac{\partial}{\partial V}\left[\frac{NkT}{V}\left\{1 + \frac{\beta}{2^{5/2}f}\right\}\right]$$

$$= -\frac{NkT}{V^2}\left\{1 + \frac{\beta}{2^{5/2}f}\right\} - \frac{NkT}{V}\cdot\frac{\beta}{2^{5/2}fV}$$

$$= -\frac{NkT}{V^2}\left[1 + \frac{2\beta}{2^{5/2}f}\right] \quad \ldots \quad (7)$$

Further

$$\left(\frac{\partial V}{\partial T}\right)_p = -\left(\frac{\partial p}{\partial T}\right)_V \Big/ \left(\frac{\partial p}{\partial V}\right)_T$$

$$= \frac{nk\left[1 - \frac{1}{2}\frac{\beta}{2^{5/2}f}\right]}{\frac{NkT}{V^2}\left[1 + \frac{2\beta}{2^{5/2}f}\right]}$$

$$= \frac{V}{T}\left[1 - \frac{5}{2}\frac{\beta}{2^{5/2}f}\right] \text{ approx} \quad \ldots \quad (8)$$

Hence equation (5) yields

$$C_p - C_V = T\left[nk\left\{1 - \frac{1}{2}\,\frac{\beta}{2^{5/2}f}\right\}\right]\frac{V}{T}\left\{1 - \frac{5}{2}\,\frac{\beta}{2^{5/2}f}\right\}$$

$$= Nk\left[1 - \frac{3\beta}{2^{5/2}f}\right] \text{ approx.} \quad \ldots \quad (9)$$

Hence

$$C_p = \frac{3}{2}Nk\left[1-\frac{1}{2}\frac{\beta}{2^{5/2}f}\right]+Nk\left\{1-\frac{3\beta}{2^{5/2}f}\right\}$$

$$=\frac{5}{2}Nk\left[1-\frac{3}{2}\frac{\beta}{2^{5/2}f}\right] \tag{10}$$

Substituting these values in equation (1) we get

$$\left(\frac{\partial T}{\partial p}\right)_H = \frac{-\frac{5}{2}\frac{\beta}{2^{5/2}f}}{\frac{5}{2}nk\left[1-\frac{3}{2}\cdot\frac{\beta}{2^{5/2}f}\right]} = -\frac{\beta}{2^{5/2}f\,nk}\text{ approx} \tag{11}$$

Hence

$\left(\frac{\partial T}{\partial p}\right)_H = \frac{1}{2^{5/2}fnk}$, i.e. positive for a gas obeying Bose-Einstein statistics

$\left(\frac{\partial T}{\partial p}\right)_H = -\frac{1}{2^{5/2}fnk}$, i.e. negative for a gas obeying Fermi-Dirac statistics

Thus the Joule-Thomson expansion leads to cooling for a gas obeying Bose-Einstein statistics and to heating for a gas obeying Fermi-Dirac statistics

From equation (11) we have, on substituting the value of f,

$$\left(\frac{\partial T}{\partial p}\right)_H = -\beta\frac{h^3}{g(2\pi m)^{3/2}\,k^{5/2}\,2^{5/2}\,T^{3/2}} \tag{12}$$

Hence we get the interesting result that the Joule-Thomson effect for a non-degenerate gas is independent of the molecular concentration n or the pressure p of the gas, and varies inversely as $T^{3/2}$

Kothari (3) has shown that the Joule-Thomson effect for a degenerate electron gas (degenerate in the sense of Fermi-Dirac statistics) is given by the relation

$$\left(\frac{\partial T}{\partial p}\right)_H = -\frac{g}{\pi kn}\left(\frac{3}{4\pi f}\right)^{2/3}$$

$$= -\frac{3^{2/3}}{2^{7/3}}\frac{h^2}{\pi^{8/3}mk^2}\cdot\frac{g^{1/3}}{Tn^{\frac{1}{3}}}$$

$$= -\frac{3}{8k^2T}\left[\frac{4gh^{12}}{15\pi^{14}m^6p}\right]^{1/5} \tag{13}$$

Thus we see that for a fixed value of T, the Joule-Thomson effect for a gas obeying Fermi-Dirac statistics varies as $p^{-\frac{1}{5}}$ for the degenerate state and

becomes constant (independent of p) when the gas becomes non-degenerate. The Joule-Thomson effect at different pressures has been calculated for *electron gas* at 5°K. and the values so obtained have been plotted in Fig. 1, where the ordinate denotes the Joule-Thomson effect in degrees/dyne and the abscissa the pressure of the gas. The degenerate state extends to the right of the vertical line A and the non-degenerate state to the left of A. In the neighbourhood of A, however, the shape of the actual curve will differ appreciably from the

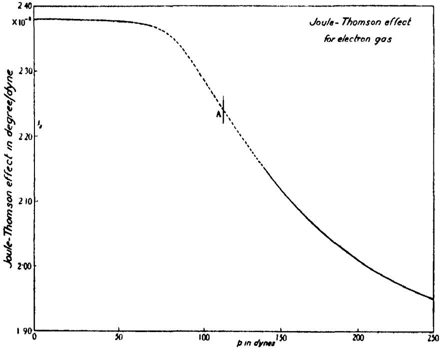

Fig. 1.

asymptotic formulæ [equation (12) for non-degenerate and equation (13) for degenerate state] and therefore this region is made dotted to indicate the general trend.

It will be of great interest to examine if the Joule-Thomson expansion can possibly afford an experimental test of the statistics obeyed by a gas. The only possible gas for which a test is possible is helium, since it is the only substance to remain in a gaseous state to very near the absolute zero in which region alone the Joule-Thomson effect due to statistical deviation becomes appreciable. But the thermal effect observed in a Joule-Thomson process is due not only to the statistical deviation from the classical perfect gas discussed above but also due to van der Waals' correction terms. We shall evaluate numerically the magnitude of these effects for helium.

Supposing helium gas obeys Bose-Einstein statistics (which we know to be a fact from band spectra data) we have

$$(\Delta T)_{\text{statis}} = \frac{(6.55\times10^{-27})^3\times1.01\times10^6}{T^{3/2}\,(2\pi\times4\times1.66\times10^{-24})^{3/2}\,(1.37\times10^{-16})^{5/2}\,2^{5/2}}\ \text{per atmos}$$

$$= \frac{0.847}{T^{3/2}}\ \text{degree/atmos} \tag{14}$$

Calculation shows that at $T = 5°$K and $p = 1$ atmos., $f = 10$, hence helium would remain almost non-degenerate. Hence at this temperature and pressure $(\Delta T)_{\text{statis}} = 0{\cdot}076°$

For a van der Waals' gas the expression for cooling, to a first approximation, is given by

$$\Delta T = \frac{1}{C_p}\left[\frac{2a}{RT} - b\right]\Delta p \tag{15}$$

Substituting the values of a and b for helium, viz. $a = 0.0341\times10^6$ atmos., $b = 23{\cdot}7$ c.c. we get for $T = 5°$K., $\Delta T = 0{\cdot}68°$ per atmos.

Using the more accurate expression, viz. :—

$$\Delta T = \frac{1}{C_p}\left[\frac{2a}{RT} - b - \frac{6ab}{R^2T^2}p\right]\Delta p \tag{16}$$

and
$$C_p = C_{p_0} + \frac{2a}{RT^2}p - \frac{3ab}{R^2T^3}p^2$$

we get for $T = 5°$K. and $p = 1$ atmosphere

$$\Delta T = 0{\cdot}57°\ \text{per atmos.}$$

As van der Waals' equation may not hold in this region we shall calculate the Joule-Thomson effect by utilizing that equation of state which is found experimentally to hold in this region. Using Kamerlingh Onnes' equation [1]

$$pV = RT\left\{1 + \frac{B}{V} + \frac{C}{V^2}\right\} \tag{17}$$

[1] L. Gropper (4) has developed the quantum theory of the equation of state at low temperatures and has deduced an expression for the second virial coefficient. For a gas obeying Bose-Einstein statistics he finds that approximately at low temperatures

$$B = -\frac{N\pi^{3/2}\lambda^3}{2} - \frac{h^2}{\pi mkT}Nf(0) - \pi Nf''(0) -$$

where $\lambda^2 = h^2/4\pi^2 mkT$. The evaluation of the function f however cannot be done without recourse to experimental data and even then the values are not free from uncertainties, and hence it is best at the present stage to use directly Kamerlingh Onnes' equation.

we can deduce, correct to small quantities of the second order, that

$$p\left(\frac{\partial V}{\partial T}\right)_p = R\left(1+\frac{B}{V}+\frac{C}{V^2}\right)+RT\left[\frac{1}{V}\frac{dB}{dT}-\frac{B}{V^2}\left(\frac{\partial V}{\partial T}\right)_p\right.$$

$$\left.+\frac{1}{V^2}\frac{dC}{dT}-\frac{2C}{V^3}\left(\frac{\partial V}{\partial T}\right)_p\right]$$

or

$$\left(\frac{\partial V}{\partial T}\right)_p = \frac{R\left(1+\frac{Bp}{RT}-\frac{B^2p^2}{R^2T^2}+\frac{Cp^2}{R^2T^2}\right)+p\frac{dB}{dT}-\frac{Bp^2}{RT}\frac{dB}{dT}+\frac{p^2}{RT}\frac{dC}{dT}}{p+\frac{p^2}{RT}B+\frac{2Cp^3}{R^2T^2}-\frac{2B^2p^3}{R^2T^2}}$$

$$= \frac{R}{p}\left[1+\frac{p}{R}\frac{dB}{dT}+\frac{p^2}{R^2T^2}\left\{B^2-2BT\frac{dB}{dT}-C+T\frac{dC}{dT}\right\}\right]$$

$$T\left(\frac{\partial V}{\partial T}\right)_p - V$$

$$= \frac{RT}{p}\left[1+\frac{p}{R}\frac{dB}{dT}+\frac{p^2}{R^2T^2}\left\{B^2-2BT\frac{dB}{dT}-C+T\frac{dC}{dT}\right\}\right]$$

$$-\frac{RT}{p}\left[1+\frac{Bp}{RT}-\frac{B^2p^2}{R^2T^2}+\frac{Cp^2}{R^2T^2}\right]$$

$$= T\frac{dB}{dT}-B+\frac{p}{RT}\left\{2B^2-2BT\frac{dB}{dT}-2C+T\frac{dC}{dT}\right\} \qquad (18)$$

A van Itterbeek (5) found that between 14 50° and 3 70°K , B is given by

$$B\times 10^3 = 0\ 7559-\frac{19\ 64}{T}-\frac{3\ 79}{T^2}+\frac{34\ 94}{T^3}$$

in Kamerlingh Onnes' units Multiplying this by $22\ 4\times 10^3$ we get B in c c mole The values of C are not very accurately known In the lower temperature region the values of C given by Keesom and Kraak (6) may be taken, while at the higher temperature C may be neglected. C_p may be calculated with the help of the approximate formula

$$C_p = C_{p_0} - Tp\frac{d^2B}{dT^2}$$

where $C_{p_0} = \frac{5}{2}R$ for helium. Making use of these results we get for $T = 5$°K. and $p = 1$ atmos.

$$\Delta T = 0{\cdot}83° \text{ per atmos.}$$

Calculations for $T = 10$°K and $p = 5$ atmos. have also been made and are given in the following table together with the values for $T = 5$°K. and $p = 1$ atmos.

TABLE 1 —JOULE-THOMSON EFFECT (μ_J) IN °C. PER ATMOS

	For $T = 5°$K. and $p = 1$ atmos.	For $T = 10°$K and $p = 5$ atmos.
μ_J statistical	0·076°	0·027°
μ_J from van der Waals' equation (first approx)	0·68	0·285
μ_J do. do (second approx)	0·57	0·262
μ_J from K Onnes' experimental equation	0·83	0·375

These results clearly show that the Joule-Thomson effect due to statistical deviation amounts to about 10% of the total expected value for the gas at these temperatures, in other words, about 10% of the cooling is contributed by the statistical effect and the remainder by van der Waals' correction terms.[1]

The experimental data on Joule-Thomson effect in helium are at present too meagre and cannot be utilized as a check to the conclusions arrived at above. The recent experiments of Roebuck and Osterberg (7) were not carried below 83°K and thus at the temperatures of their experiment the statistical effect would be imperceptible.

Jacyna (8) in a number of papers has calculated the Joule-Thomson effect and the inversion curve for helium on the basis of his thermodynamic equation of state. He has however not given the values of μ_J in the range of temperatures discussed here. He finds that μ_J will be zero at all temperatures for $p \rightarrow 0$. We have seen here that due to the quantum statistical effect μ_J will not be zero even at $p \rightarrow 0$ as van der Waals' equation might suggest but will approach a limiting constant value, the value depending upon the temperature For high temperatures the value is extremely small and hard to detect experimentally but at $T = 5°$ or 10°K it can possibly be detected As already mentioned, no experiments in this region have yet been carried out.

My best thanks are due to Prof M N Saha, F.R.S., for his kind interest in the work, and to Dr D. S Kothari of Delhi University for a discussion of the problem.

SUMMARY.

An expression for the Joule-Thomson effect in the case of a non-degenerate gas has been derived. According to this the Joule-Thomson expansion will

[1] Since the value of μ_J calculated from the experimental equation of state is always greater than that calculated from van der Waals' equation, it follows that the calculated values are perfectly consistent with the view that helium obeys Bose-Einstein statistics. Exact verification can only be done when the exact contribution of van der Waals' terms is separately known. This is not possible at present.

lead to cooling for a gas obeying Bose-Einstein statistics, while for a gas obeying Fermi-Dirac statistics it will produce heating The magnitude of this effect varies as $T^{-3/2}$ and is independent of pressure. For the sake of comparison the Joule-Thomson effect has been calculated for helium at certain temperatures on the basis of van der Waals' equation and K Onnes' experimental equation. It is found that at 5°K. the Joule-Thomson effect due to statistical deviation, i e. deviation from the classical perfect gas state due to effect of quantum statistics, amounts to about 10% of that calculated from K Onnes' experimental equation of state, while at 10°K it is 8%. It is suggested that the Joule-Thomson expansion of helium gas at very low temperatures may afford an experimental test of the statistics obeyed by this gas

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THE CHEMICAL FIXATION OF NITROGEN AT LOW TEMPERATURE AND ITS SIGNIFICANCE IN AGRICULTURE

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(Communicated by Rao Bahadur B Viswa Nath)

(*Read November 6, 1937*)

Work on nitrogen transformations in the soil has established three facts

1. Fixation of atmospheric nitrogen following the oxidation of carbohydrate materials
2. Oxidation of ammonium compounds to nitrates
3. Loss of nitrogen

The oxidative processes which are believed to be mainly brought about by micro-organisms may be represented by the following main reactions Starting with urea the degradation product of proteins —

$$CO(NH_2)_2+2H_2O = (NH_4)_2CO_3$$
$$2NH_3+3O_2 = 2HNO_2+2H_2O$$
$$2HNO_2+O_2 = 2HNO_3$$
$$2HNO_3 = 2HNO_2+O_2$$
$$4HNO_2 = 2H_2O+2N_2+O_2$$

Energy relations are important considerations in the process and the micro-organisms concerned utilize carbohydrates and proteins of the organic matter present in the soil as sources of energy

Recently Dhar and his associates (Influence of light on some Biochemical Processes, *Society of Biological Chemists, India*, 1935) have put forward the view that light energy is concerned in the process of nitrification and that the process is partly biological and partly photo-chemical This view is corroborated by Corbet, (*Biochem Jour*, *28*, 1934) and others, while Fraps and Sturges (*Soil Sci*, 1934), Joshi (*Sci Reports, Imp Agri Res Inst*, 1934-35) and others deny photo-chemical nitrification Joshi on the other hand observed decomposition of nitrates in light.

Viswa Nath (*Presidential Address, Agric Section, Indian Science Congress*, 1937) has drawn attention to the apparently conflicting processes of oxidation of ammonia and losses and gains of nitrogen occurring in the soil, and suggested a re-examination of the whole problem, particularly in regard to the significance of nitrogen loss which appears to be followed by nitrogen fixation In the course of studies on soil nitrogen which are in progress at the Imperial Agricultural

Research Institute, it occurred to the author that the chemical energy of oxidation might in some way be concerned in the process.

In reviewing the literature on chemical chain kinetics especially phosphorous oxidation first studied by Van Marum (*Ann Chim. Phys.*, 1799) up to Melville (*Trans. Faraday Soc.*, *28*, 2, 815, 1932), it is now established that Phosphorous oxidation is definitely propagated by energy chains and by collision with other molecules these chains are broken. The effect of various gases in changing the critical pressure limits has been thoroughly investigated by others. But the question as to what happens to the energy of these chains in a deactivating collision with another molecule has not been touched upon so far.

Experimental.—Shönbein (Poggendorf's *Annalen*, 1845, *65*, 69) first recorded the formation of hydrogen peroxide and ozone when moist P is oxidized in air Russel (*J C.S.*, *83*, p 1263; 1903) studied oxidation of moist phosphorous and mentioned that, in addition to ozone and H_2O_2, ammonium nitrite and nitrate are also formed, but he has not given experimental evidence in support of this statement.

Experiments with phosphorous—5 gms. of phosphorous were placed in a bulb and air which was first purified by passing through two bottles each of sodium hydroxide, sulphuric acid and 5% solution of ferrous sulphate in dilute H_2SO_4, was passed slowly over the phosphorous in the bulb and the products of reaction were caught in 2N solution of sodium hydroxide There was a side feeder of purified air joining the products of reaction in their passage from the bulb to the absorption vessels. The sodium nitrite formed was estimated colorimetrically with Lunge's modification of Greiss-Illosway reagent. The oxidation may be represented as—

$$N_2+O_2 \rightarrow 2NO$$
$$2NO+O_2 \rightarrow 2NO_2$$
$$NO_2+NO \rightarrow N_2O_3$$

The rate of passage of air and the amount of moisture present appear to influence the yields. The yields are more with slower oxidation and greater moisture in the system. Typical results of several experiments are given below :—

Nature of experiments.	Mgm N as N_2O_3.
1. Very rapid flow of air ..	Nil
2. At 150 bubbles of dry air per 2 minutes 40 seconds	0·01
3. At 150 bubbles of moist air per 2 minutes 40 seconds over phosphorous ..	0·02-0·03
4. At 150 bubbles of moist air per 2 minutes 40 seconds over moist phosphorous .. .	0·04-0·05

Experiments with tin and magnesium.—The air feeder being cut off, and when foils of metals, tin and magnesium were exposed to the issuing products

of the above reaction, the exposed surface of the metal was completely covered with the nitride

When 0·8 gm of tin was used in the experiment, 0 6 mgm. of nitrogen was fixed If more surface could be exposed more nitrogen would probably have been fixed. The nitride of metals was also detected in the oxidation of potassium, but the rapid formation of a protective layer of the peroxide prevented further study.

Experiments with cane sugar —When the products of phosphorous oxidation are passed over moistened Merck's extra pure cane sugar with the side feeder of air, 0·25$\pm$0 01 mgm of nitrogen was fixed

Thus at ordinary air temperature the N_2 present in an oxidation system is capable of becoming active and combining with metals, oxygen and other substances as the case may be

The next experiment was carried out with Merck's cane sugar oxidation instead of phosphorous, but in this case at high temperatures (50°C and 96°–98°C.) by passing a current of purified air for 48 to 72 hours. Large quantities of ammonia were detected with Nessler reagent as against blanks The results of the experiments using 4 gms. of moist sugar spread in a U tube at 98°C. were :—

No of hours	Mgm. of nitrogen as NH_3	Mgm of nitrogen as N_2O_3
65	0·06	0·07
65	0 05	0 08
68	0 075	0 084

These results with cane sugar are in conformity with the findings of Dhar and his associates (*Proc. Nat. Acad Sci , Allahabad*, 19th Dec., 1935), the only difference being that the influence of light, micro-organisms and catalysts (particularly ferrous iron itself in the oxidation of which ammonium salts were reported by Russel, 1903) is eliminated and that the nitrogen fixed is related simply to oxidation of sugar only N_2O_3 was also detected with the Greiss reagent Further work is in progress on the quantitative relationship between carbon oxidized and nitrogen fixed merely as the result of chemical oxidation.

An experiment on the reciprocal process of carbon fixation resulting from ammonia oxidation in unsterilized soil has given a result of 50$\pm$4·5 mgm of carbon fixation but this needs further verification.

These experiments point to the possibility of oxidation and reduction processes in biological systems by direct energy transfers. Apart from their theoretical interest in explaining some gaps in our existing knowledge, they are of considerable practical importance to agriculture. Considering for example the work on carbon assimilation in *vitro*, Baly (*Proc. Roy. Soc.* A *116*, p. 212 ; 1927) has worked out the energy relations of photo-synthesis. For a

single gram molecule of hexose sugar formed from CO_2, 673,800 calories are at least required, while the living leaf achieves this by the absorption of 263,000 calories even, under the influence of red light The question of absorbing more quanta is improbable (Kohn, *Nature*, *137*, p 706, 1936) This difference may at least be accounted for partly if the energy of simultaneous oxidative processes is taken into consideration. It may explain the Blackman reaction in a new fashion (Emerson, *Ann Rev Biochem*, 1937, p 538) and also the absolute necessity of O_2 for photo-synthesis emphasized by Willstätter and Stoll ('Untersuchungen über die Assimilation', Berlin, 1918, p 348), the significance of the internal factors other than the chlorophyl content and the not always convincing results of photo-synthesis in vitro of several workers (Spoehr, *Ann. Rev Biochem*, 1933, p 463) by merely exposing carbon dioxide and water without providing for an additional source of oxidation energy, just as, for example, ammonia oxidation is used by some micro-organisms for carbon fixation

In regard to nitrogen fixation in soils, the fixation through chemical oxidation may explain nitrogen fixation in the hot months of May, June and July (Bal, *Proc. Nat Inst Sci India*, *3*, p 57, 1937); it may also explain the beneficial advantages of moderate ploughing of the soil, although Leather (*Mem Dep Agri India, Chem. Series*, *14*, No 3, p 134, 1915) has shown that gaseous exchange occurs in soils to a depth of 1 ft. It suggests also a new orientation to the problem of nitrogen conservation from the point of view of the conditions necessary for an effective transfer of chemical energy by means of collision between molecules of nitrogen and the energy source

I take this opportunity to record my deep sense of gratitude to Rao Bahadur B Viswa Nath, F.I C, F N.I., for his great help and valuable guidance in the entire course of this work

A STUDY OF THE BEHAVIOUR OF SOME COMMON VARIETIES OF SUGARCANE IN REFERENCE TO THE ATTACK OF BORERS AT PUSA (BIHAR) DURING 1935-36

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(*Read November 6, 1937*)

INTRODUCTORY

The cultivation of sugarcane has rapidly extended during the last ten years in almost all the cane-growing tracts of India The extension in the cultivation of this valuable crop has naturally brought its insect pests into great prominence Borers constitute the most serious pests Reports from various parts of the country indicate that on an average about 10% of the crop is damaged by these pests every year Recent work in several countries has shown that all cane varieties are not equally susceptible to damage by borers [Cleare, (1934), Holloway, (1935), Tucker, (1936), etc] In India numerous new varieties of cane are distributed periodically from Coimbatore for trial in the provinces and it is of great economic importance to ascertain, in addition to other factors, the behaviour of such varieties towards insect pests in different regions of the country Observations on this aspect of the problem have been taken on several varieties at Pusa [1] and some localities in the Punjab [1] during the last five or six years and at Muzaffarnagar (United Provinces) for the last one year or so,[1] but in most cases the observations have been based on only a small number of canes of a few varieties at a time As far as the available literature shows, hardly any critical large-scale investigation, to study the comparative susceptibility of the most common varieties of an area while grown side by side, has yet been undertaken at any station in the country Therefore in the cane season of 1935-36, while the Imperial Agricultural Research Institute was still at Pusa, a study into the behaviour of the five common varieties of cane of North Bihar was made, the results of which are described in the following pages.

MATERIAL AND METHODS

The varieties under study were Co 210, 213, 299, 313, and 331. They were planted in a randomized plot about two acres in size in the Harpur jilli

[1] See the Annual Reports of the Imperial Entomologist, Pusa, and those of the Director of Agriculture, Punjab, for the years 1930–36, and of the Director of Agriculture, United Provinces, for 1935-36.

field of the Pusa Estate. The detailed plan of the layout (Fig. 1) was as follows :—

The plot was divided into eight blocks and each block was sub-divided into five divisions, each division measuring 60′×24′, with a six feet broad passage all round. Each division contained one particular variety and the planting was done in such a way that each block contained all the five varieties, labelled A, B, C, D, and E, in the figure. Planting was done in all the divisions lengthwise (east to west) in rows three feet apart from one another as shown in D of block No. 8 in Fig. 1. Thus there were eight rows of each variety in a division and the various varieties were distributed in the blocks at random. Four (Nos. 1–4) out of the eight blocks were kept as controls,

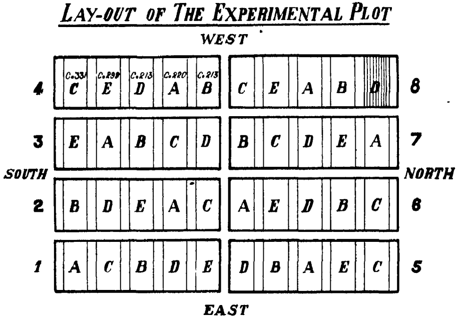

FIG. 1.

whereas in the other four (Nos. 5–8) the dead hearts (external symptoms of borer attack) caused by various borers were removed and their causal agent examined and determined every month Thus data about the number of dead hearts appearing every month and the kind of borer or borers responsible for them were obtained. Two hundred canes of each variety from each division, viz. 800 canes of each of the five varieties, were thus examined every month. In the control blocks the total number of dead hearts observed every month was recorded but no dead heart was actually removed.

The borers found infesting the crop at Pusa were of the following species :—

Top-borer—*Scirpophaga nivella* Fab. Occasionally a few specimens of *S. monostigma Zell.* were also obtained.

Stem-borers—*Diatraea* (*Argyria*) *sticticraspis* Hmp. was the most common species (80–85%); *D venosata* Wlk was about 15% and *Chilo zonellus* Swinh 3–5% The seasonal history and habits of the three species were almost similar and therefore they were considered as one pest.

Root-borer—*Emmalocera depressella* Swinh

OBSERVATIONS

The observations on the incidence of pests on various varieties in different blocks throughout the year are detailed in Table I The same observations are summarized in Table II, in which the data from different blocks have been pooled together In Tables III–VII the observations on each of the five varieties under investigation have been tabulated separately, so that the behaviour of a particular variety at different times of the year can be examined readily. The data given in these five tables are graphically shown in Figs 2–6, so that the reader can easily have an idea of the behaviour of various pests at different times of the year infesting a particular variety In Figs 7 and 8 the increase in the aggregate number of dead hearts during different months is shown graphically. The observations are summarized below.

THE STEM-BORER.

The stem-borer moths emerging from the hibernating larvæ of the previous season were first seen in the cane fields early in March and they started ovipositing soon afterwards. The young larvæ started boring into the stems within a week and dead hearts, the external symptoms of their attack, began appearing in April. The same was observed by the staff of the Imperial Entomologist during the previous five years The percentages of dead hearts caused by this pest in various varieties during different months of the year are given in Table II, column 6. During April this percentage varied between 0·16 and 0·57. With the onset of summer the activity of this pest increased and the greatest number of dead hearts in all varieties caused by this borer were observed during June (2·75%–6·75%) From July onward the activity of stem-borer remained at a low ebb (Figs. 2–6), and the pest was not responsible for causing more than 2 5% of dead hearts in any month in any variety (Tables III–VII)

With regard to the comparative susceptibility of various varieties to the attack of stem-borer, Co 213 proved to be the most susceptible. During June, when all the varieties had the highest number of dead hearts caused by this pest, Co. 213 had 6·75%, Co. 210 came next (5·33%), Co. 331 had 3·63%, and Co. 313 showed the least damage (2·75%). During the rest of the year also (Table II, column 6) the various varieties showed damage in the same order of intensity as above. Though Co. 299 and Co. 313 were equally damaged during June, the latter variety was however more damaged during the rest of the year, therefore keeping the whole year in view, Co. 299 proved to be the most resistant.

THE TOP-BORER.

As observed by the staff of the Imperial Entomologist during the previous five years or so, the top-borer moths also emerged and started laying eggs in March, and the dead hearts caused by the borer larvæ began appearing during April. The number of dead hearts caused by this pest gradually increased during May and June (Table II, column 5), but during July there was a sudden increase when the percentage of dead hearts in the various varieties varied between 5·38 and 9·63 After this month there was a fall in the case of all

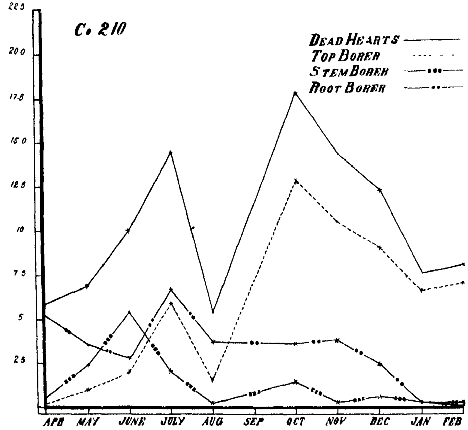

FIG. 2 Percentage of dead hearts caused by all borers (shown by straight line) and by various borers individually at different times of the year in Co 210

varieties (Tables II–VII), probably due to the monsoon, the highest percentage during August being 2·25. The number of dead hearts observed in October (9·13%–12·83%) represented figures for two months, as no observations had been taken during September due to floods Even keeping this fact in view, the increase in the number of dead hearts in the beginning of autumn was evident, as during November the percentage varied between 5·88 and 11·38 There was a slight decrease after this month, but the percentage remained at

a high level throughout the winter Thus unlike the stem-borer, the top-borer was active almost throughout the year except during the monsoon months, and was most serious at the height of summer and then again in autumn (Figs 2–6)

As regards the comparative susceptibility of the various varieties, it will be evident from a perusal of Table II, column 5, that whereas up to the end of July this pest caused almost the same percentage of dead hearts in all the varieties, after the rains the variety Co 210 suffered the most during the rest

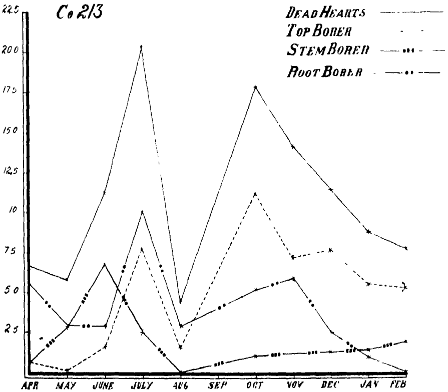

FIG 3 Percentage of dead hearts caused by all borers (shown by straight line) and by various borers individually at different times of the year in Co 213

of the season Co 213 behaved slightly better than Co 210, Co 299 came next, and Co 313 and 331 proved to be most resistant

THE ROOT-BORER

The moths of this pest as those of the previous ones were observed in fair numbers in the field in the first week of March and dead hearts caused by the borer larvæ appeared in April At this time the root-borer was responsible for causing a much higher percentage (3 63 to 5·75) of dead hearts in all varieties than stem- and top-borers taken together (Table II, cf column 7 with 6 and 5

and Tables III–VII). During May the position was almost unchanged. In June the percentage of dead hearts went down slightly, but it considerably increased again during July (5·25—11·75%), obviously due to the attack by the second brood of the pest. At this time again, of the dead hearts examined, more were caused by the root-borer than by the top- and stem-borers together. During the monsoon months the damage caused by this pest was less, as was the case with other borers described above. There was a slight increase during October and November, but it was never so high as during the summer months

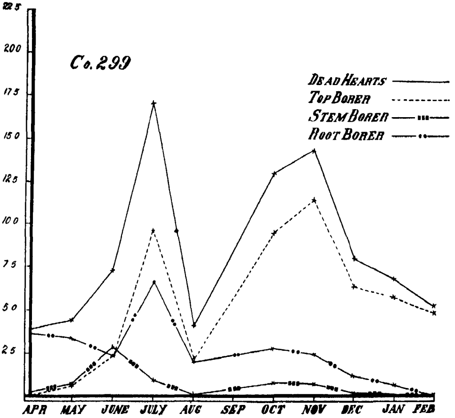

FIG 4 Percentage of dead hearts caused by all borers (shown by straight line) and by various borers individually at different times of the year in Co. 299.

(Table II, column 7 and Figs. 2–6) From the beginning of December onwards there was very little damage by the root-borer (0·38%–2·5%).

As regards the relative susceptibility of various varieties, Co. 331 proved to be the most susceptible to the attack of this pest throughout the year. Co. 213 was slightly less susceptible. During July, when the percentage of dead hearts caused by the root-borer was the highest, these two varieties had 11·75% and 10·23% of dead hearts, whereas in each of the other three varieties dead hearts were about 6·5% only. Though in July these three varieties had

almost the same percentage of dead hearts, their behaviour studied throughout the year (Tables II–VII) showed that of the three Co 210 suffered the most Thus Co. 299 and Co 313 proved to be the least susceptible to the attack of this pest.

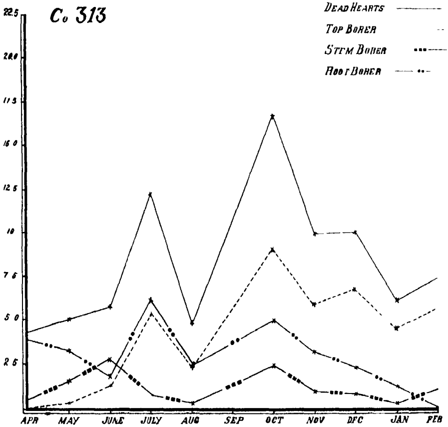

FIG 5. Percentage of dead hearts caused by all borers (shown by straight line) and by various borers individually at different times of the year in Co 313

AGGREGATE DEAD HEARTS IN THE CONTROL PLOTS.

As has been stated in the beginning of this article, 800 canes of each variety were examined every month also from the control blocks, in the same way as from the experimental blocks, except that in the former case the dead hearts after counting were not removed and their casual agents not determined. The control plots therefore presented the natural condition The percentage of accumulating or aggregate dead hearts in various months in different varieties is graphically shown in Fig. 7, whereas the monthly increase in dead hearts every month is shown graphically in Fig. 8 It will be observed that as the season advanced the number of dead hearts increased and did so suddenly in June and July (see Fig. 8) and then rapidly decreased in

the succeeding months Figure 7 shows that Co 210 suffered the greatest amount of damage, and Co. 299 the least.

Furthermore, it appears from Fig. 8 that the new dead hearts that were formed each month in the control blocks were not so numerous as those which appeared in the experimental blocks in which all the new dead hearts were removed every month. This suggests that the removal of dead hearts from a particular field does not help much to check the damage if similar action is not taken in the surrounding fields from where the pests can have free access to the fields which are made practically pest free.

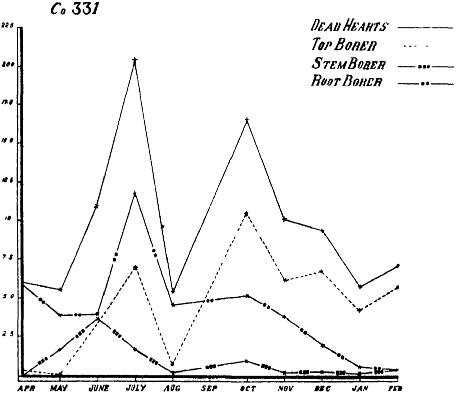

FIG 6 Percentage of dead hearts caused by all borers (shown by straight line) and by various borers individually at different times of the year in Co 331

CONCLUSIONS AND SUMMARY.

From the foregoing it will be observed that all the three borers begin their activity at Pusa during March. They become more numerous with the approach of the hot weather. This might be due to the normal increase in the number of the pest, inasmuch as early in May there is a second brood of the moths in the field which is naturally much bigger than the initial one, or it may be due to the influence of the hot dry weather During the monsoon months the damage by all borers decreased but increased again soon after

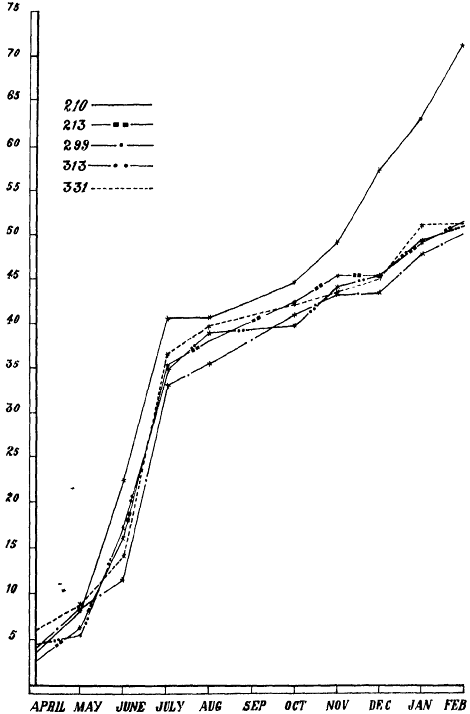

FIG. 7. Percentage of aggregate dead hearts at different times of the year in various varieties.

the rains were over. The increase in the activity of borers during autumn was especially well marked in the case of the top-borer, which caused in almost all the varieties examined more damage at this time than even at the height of summer. Furthermore, when the winter set in, whereas there was considerable decrease in the damage caused by stem- and root-borers, the damage by top-borer remained at a fairly high level. These observations confirm those already taken by the staff of the Imperial Entomologist during 1930–35 (*op. cit*.).

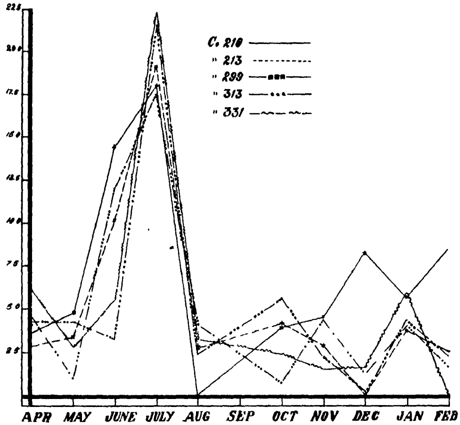

FIG. 8. Monthly increase in dead hearts in various varieties

As to the cause of the difference in behaviour of the various borers, apart from the peculiar biology of individual pests, the stage of growth of the cane seems to play a very important part. As the top-borer attacks the growing region of the plant, it is active throughout the growth of the cane. The stem- and root-borers which attack the stem and basal parts of the plant as long as they remain soft, cause most damage in the early stages of the crop, viz. till the onset of the monsoon. After this period they mostly attack the tillers, which are usually given out up to the end of November.

As regards the relative susceptibility of the various varieties under investigation, only tentative conclusions can be drawn at present, as extensive and properly planned observations have been taken during one season only The data collected and summarized in the previous pages indicate that a particular variety may be resistant to one borer and susceptible to another For example, the variety Co 331 was found to be most susceptible to the attack by the root-borer but very resistant to that by the top-borer. In the following table the various varieties have been arranged in order of merit, in reference to their susceptibility to the attack of different borers, as observed in 1935-36

	Stem-borer	Top-borer	Root-borer
Least susceptible . . .	Co 299 Co 313	313 331	299 313
	Co 331	299	210
	Co 210	213	213
Most susceptible . .	Co 213	210	331

Taking all the borers into consideration, the varieties Co 313 and Co 299 seemed to be most resistant, Co 331 intermediate, and Co 213 and Co 210 the least resistant.

ABSTRACT.

The fact that certain varieties of crops are resistant to insect attack has been established on general lines for some time past. Sugarcane which is one of the most valuable crops in India is seriously damaged by certain moth borers every year In other countries, e g the West Indies, etc , where this crop is also attacked by borers, belonging to allied species, it has been found that certain varieties are more resistant to the attack of these pests than others In India a large number of Coimbatore cane varieties are distributed every year and are tested in various provinces with regard to their yield, etc. Only occasional observations have been taken on their behaviour in reference to insect pests Therefore, a detailed study from this view-point of the most common cane varieties of North Bihar was made at Pusa during 1935-36, the results of which are described in the paper

The five common varieties Co. 210, Co 213, Co 299, Co 313 and Co 331 were critically studied. They were grown side by side in a randomized plot and about 800 canes of each variety selected from various parts of the field were examined every month for dead hearts (the external symptoms of borer attack), which were dissected and their causal borer determined The number of fresh dead hearts appearing in each variety during different months of the year were noted. Examination of the data thus collected lead to the following general conclusions —

Moths of all the three borers, viz top-, stem- and root-borers emerge in the field in March They lay eggs soon afterwards and the young borers hatching therefrom attack different parts of the cane and cause dead hearts

which appear during April. As the season advances all the three borers become more active and cause the maximum number of dead hearts during June or July. During the monsoon months their activity decreases but soon after the rains are over it increases again. The damage by the top-borer is especially very heavy during autumn. This pest remains active almost throughout the year, whereas the dead hearts caused by the stem- and root-borers during winter are comparatively few. These results are in accordance with the observations taken by the staff of the Imperial Entomologist during the last five years or so.

As regards the comparative susceptibility of various varieties, the conclusions derived are yet only tentative as the varieties have been studied on a large scale and under properly planned experiments for one season only. Taking all the borers into consideration, Co. 313 and Co. 299 seem to be the most resistant, Co. 331 intermediate, and Co. 213 and Co. 210 the least resistant.

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The number of dead hearts caused by different borers in various varieties in

Time of year	Varieties	Block 5: No. of plants examined	Block 5: Dead hearts %	Block 5: Top-borer %	Block 5: Stem-borer %	Block 5: Root-borer %	Block 5: Borers in combination %	Block 6: No of plants examined	Block 6: Dead hearts %	Block 6: Top-borer %	Block 6: Stem-borer %	Block 6: Root-borer %	Block 6: Borers in combination %
1	2	3	4	5	6	7	8	9	10	11	12	13	14
April	Co 210	200	1·5	0·5	0 5	0·5							
	Co 213	200	11·0	1·5	1·0	8 5		100	3 00			3 00	
	Co 299	200	1 5		0 5	1 0		33	9 90			9 90	
	Co 313	200	2·0		0 5	1·5		57	3 51		1·76	1 76	
	Co 331	200	7·0	1·0		6 0		200	5 0			5·0	
May	Co 210	200	4·0	1 0	2 5	0·5							
	Co 213	200	7 0	0·5	3 5	3 0		200	5 0		3·0	2	
	Co 299	200	2·0		0 5	1 5		131	6 11	2 29		3 82	
	Co 313	200	6·5	0 5	2 5	3 5		200	5·0	0 5	2 0	2 5	
	Co 331	200	7·0		2 5	4 5		200	2 5		0 5	2·0	
June	Co 210	200	2 0		1 0	1 0		200					
	Co 213	200	6 0	1 5	3 5	1 0		200	6 5		3 5	3·0	
	Co 299	200	7 5	4 5	2·5	0·5		200	8 0	1 5	3 5	3 0	
	Co 313	200	10 0	3 0	3 5	3 5		200	2 5		2 5		
	Co 331	200	10 0	4 0		6 0		200	9 5	1·5	6 0	2 0	
July	Co 210	200	12 0	5 0	1 5	5·5		200					
	Co 213	200	20 5	9 5	3 0	8 0		200	20 0	9 0	3 5	7 5	
	Co 299	200	13 0	7 0		6 0		200	22 5	20 5	2 0		
	Co 313	200	14 0	5 5	1 5	7 0		200	9 5	5 5	1 0	3 0	
	Co 331	200	29 5	17 0	4 0	8 5		200	20 5	2 0	2 0	16 5	
August	Co 210	200	4 0	1 5	0 5	2 0		200					
	Co 213	200	3 5	2 0		1 5		200	5 0	1 0		4 0	
	Co 299	200	4 0	1 0		3 0		200	5 5	2 5		3 0	
	Co 313	200	6 5	4 5	0 5	1 5		200	3 0	1 0		2 0	
	Co 331	200	4 5			4 5		200	4 5	1 5		3 0	
September	No observations taken												
October	Co 210	200	9·5	6·0	1 0	2 0	0 5	200					
	Co 213	200	17 0	10 5		5 0	1 5	200	19 0	10 5	1·0	7 5	
	Co 299	200	8 0	8·0				200	10 5	7 5	1 5	1 5	
	Co 313	200	9·5	5 5	1·0	3 0		200	21·5	9 5	4 5	7·0	0·5
	Co 331	200	9 0	7 0	0 5	1·5		200	16 0	9 0		7 0	
November	Co 210	200	9·5	7·5	0 5	1·5		200					
	Co 213	200	10·0	5·5		4 5		200	21 0	8 5	4 5	8 0	
	Co 299	200	10 5	10 0		0 5		200	9·5	6 0	0 5	3·0	
	Co 313	200	9 5	6·5	1 5	1·5		200	10 0	4 5		5 5	
	Co 331	200	7·0	4·5		2 5		200	10 0	6 0	0 5	3·5	
December	Co 210	200	11·0	7·5	0 5	2·0	1 0	200	..				
	Co 213	200	12 0	6 5	3 0	2·5		200	9 0	6 5	0 5	2·0	
	Co 299	200	9 0	7·0		1 0	1 0	200	6.0	6 0	.		
	Co 313	200	11 0	7 0	0·5	3·5		200	7 5	5·5	0 5	1 5	.
	Co 331	200	9·5	7 5	.	1·5	0 5	200	5·5	4 5		1 0	.
January	Co 210	200	11 0	9·0	0·5	0·5	1·0	200		.			
	Co 213	200	9·0	6 0	1·5	0 5	1·0	200	8 0	4 5	2 0	1·5	
	Co 299	200	5·0	4 5		0 5		200	4·5	4·5			
	Co 313	200	5·5	5 0	0·5	.		200	4 0	3·5	.	0·5	
	Co 331	200	3 0	2 5			0 5	200	5·0	4 5	.		0 5
February	Co 210	200	7·5	6 5		.	1 0	200			.		.
	Co 213	200	7·5	5 0	2 5	.		200	7·5	3·0	3·5	.	1·0
	Co 299	200	7·5	6·5	..		1 0	200	2·5	2·5	..	..	..
	Co 313	200	9·5	6·0	2·5		1 0	200	8·5	6 5	1 0	..	1·0
	Co 331	200	9·5	6·5	0·5	1·5	0·5	200	5·5	5·0	..	..	0·5

individual blocks at different times of the year

Block 7						Block 8						Control (Blocks 1–4)	
No of plants examined	Dead hearts %	Top-borer %	Stem-borer %	Root-borer %	Borers in combination %	No of plants examined	Dead hearts %	Top-borer %	Stem-borer %	Root-borer %	Borers in combination %	No of plants examined	Dead hearts %
15	16	17	18	19	20	21	22	23	24	25	26	27	28
200	13 0	.	1	12 0		200	3 0			3		800	3 63
200	8·0	0 5	1	6 5		200	3 0			3		800	2 85
200	5 0			5 0		200	4 0			4		800	4 25
200	3 5			3 5		200	7 5		0 5	7		800	4 5
200	6 0			6 0		200	6 0			6		800	6 13
200	12 0	2	2 5	7 5		200	4 5		2 0	2 5		800	8 38
200	5 0		3 5	1 5		200	6 0		1 0	5 0		800	6 25
200	3 0			3 0		200	7 0	0 5	1 5	5 0		800	8 5
200	5 5		1 5	4 0		200	3 0			3 0		800	5 5
200	4 0			4 0		200	8 5		3 5	5 0		800	8 88
200	18 0	4·0	10 5	3 5		200	10 0	2 0	4 5	3 5		800	22 75
200	16 0	2·5	8 5	5 0		200	16 5	2 5	11 5	2 5		800	16 38
200	4 5	1 0	1 5	2 0		200	9 0	2 0	3 5	3 5		800	11 75
200	6 0	1 0	3 0	2 0		200	4 5	1 0	2 0	1 5		800	17 5
200	6 0	0 5	4 5	1 0		200	18 0	7 5	4 0	6 5		800	14 38
200	14 0	5 0	2 0	7		200	17 5	7 5	2 5	7 5		800	40 75
200	15 5	5 0	2 5	8		200	25 5	7 5	1 0	17 0		800	35 50
200	16 5	7 0	0 5	9		200	16 5	4 0	1 0	11 5		800	33 25
200	13 0	5 0		8		200	12 5	5 5		7 0		800	35 0
200	16 0	6 5	0 5	9		200	15 5	2 5		13		800	36 63
200	3 0	1 0		2 0		200	9	8 5		0 5		800	40 78
200	5 0	1 5		3 5		200	4	1 5		2 5		800	38 25
200	3 0	2 5		0 5		200	3 5	2 5	.	1 0		800	35 63
200	5 5	2 5		3 0		200	4	1		3 0		800	39 13
200	7 0	0 5	0 5	6 0		200	5 5	1		4 5		800	39 88

due to floods

200	20 5	15 5	1 5	3 5		200	23 5	17 0	1 5	5 0		800	44 75
200	17 5	13 0	1·0	3 5		200	17 5	11 0	2 0	4 5		800	42 63
200	12 0	6 0	0 5	5 5		200	21 5	16 5	1 0	4 0		800	41 25
200	21 0	13 0	0 5	7 5		200	14 5	8 5	3 5	2 5		800	39 88
200	20 5	11 5	2 0	7 0		200	20 5	14·5	1 0	5·0		800	42 25
200	11 0	7·0		4 0		200	22 5	17 0		5 5		800	49 25
200	13·5	6 5		7 0		200	12 0	8 0		4·0		800	45 5
200	10·5	7 0	1 50	2 0		200	27·0	22 5	0 5	4 0		800	43 5
200	9·5	6 5	0 5	2 5		200	10 5	6·0	1 5	3 0		800	44 25
200	9·0	4 0		5 0		200	14 0	10 0		4 0		800	45 38
200	10 5	7 5	0 5	2 0	0 5	200	15 5	12 0	0 5	3		800	57 5
200	11 5	9 0	1 0	1 5		200	13·0	8 5	0·5	4		800	45 4
200	8·5	6 5		1 5	0 5	200	8·5	6 0	0 5	2		800	43 63
200	11 5	7 0	0 5	3 0	1 0	200	10 0	7 5	1·5	1		800	45·5
200	9 0	7·0		2 0		200	13·0	8·0	1 0	3	1	800	45 38
200	5 0	5	.			200	6 5	5 5			1	800	63 13
200	10·5	7	0 5	1·0	2	200	7·5	4·5	1 5	0 5	1	800	49 25
200	9 0	7		2 0		200	9 0	7·0			2	800	48
200	7·5	4		3 5		200	7 0	5 5		0 5	1	800	49 50
200	5 5	3	0·5	2 0		200	9 0	7 0			2	800	51·25
200	9 0	7·5	0 5		1 0	200	7·5	7 0			0·5	800	71 50
200	8·5	7·0	1 0		0 5	200	7·5	6 0	0 5		1 0	800	51·50
200	5·5	5·5		.		200	5 5	5·0		.	0·5	800	50·25
200	7 0	5 5	0·5		1·0	200	4 5	4·5			.	800	51·13
200	8·5	7·0	1·0	.	0 5	200	4 5	4 5	..		.	800	51·25

Table 11.

The total number of dead hearts caused by borers in various varieties in all the experimental and control blocks.

Time of year.	Experimental blocks.							Control blocks.	
	Varieties.	No. of plants examined	Total % of dead hearts.	Dead hearts caused by top-borer %.	Dead hearts caused by stem-borer %.	Dead hearts caused by root-borer %.	Dead hearts caused by borers in combination %.	Aggregate dead hearts %.	Remark
1	2	3	4	5	6	7	8	9	10
April	Co 210	600	5 83	0·17	0·50	5 17		3 63	In the control blocks 800 plants were examined every month
	Co 213	700	6 71	0 57	0·57	5 56		2 85	
	Co 299	633	3 79		0 16	3 63		4·25	
	Co 313	657	4 26		0 46	3 81		4·5	
	Co 331	800	6·00	0 25		5 75		6 13	
May	Co 210	600	6 83	1 00	2 33	3 50		8 38	
	Co 213	800	5 75	0 13	2 75	2 88		6 25	
	Co 299	731	4 38	0 55	0 55	3·28		8 50	
	Co 313	800	5·00	0 25	1 50	3·25		5 50	
	Co 331	800	5 50		1 63	3 87		8 8	
June	Co 210	600	10 00	2 00	5 33	2·67		22 75	
	Co 213	800	11 25	1 63	6·75	2 88		16 38	
	Co 299	800	7 25	2 25	2 75	2 25		11 75	
	Co 313	800	5 75	1 25	2 75	1 75		17 5	
	Co 331	800	10 88	3 38	3 63	3·88		14 38	
July	Co 210	600	14 50	5 83	2·00	6 67		40 75	
	Co 213	800	20·38	7 75	2 50	10 13		35·50	
	Co 299	800	17 13	9 63	0 87	6 63		33 25	
	Co 313	800	12 35	5 38	0 63	6 25		35 00	
	Co 331	800	20 38	7 00	1 63	11 75		36 63	
August	Co 210	600	5 33	1·50	0·17	3 67	.	40 78	
	Co 213	800	4 38	1·50		2 88		38·25	
	Co 299	800	4 00	2 13	.	1 87		35·63	
	Co 313	800	4·75	2·25	0 13	2 38		39·13	
	Co 331	800	5 38	0·75	0 13	4 50		39·88	
September	No observation taken due to floods.								
October	Co 210	600	17 83	12 83	1·33	3 50		44 75	
	Co 213	800	17·75	11 25	1 00	5·13	.	42·63	
	Co 299	800	13 00	9 50	0 75	2 75		41·25	
	Co 313	800	16 63	9 13	2·38	5 00		39·88	
	Co 331	800	16 50	10 50	0 88	5·13		42·25	
November	Co 210	600	14·33	10 50	0 17	3 67	.	49·25	
	Co 213	800	14·13	7 13	1·13	5 88	..	45·50	
	Co 299	800	14 38	11·38	0·63	2 38		43·50	
	Co 313	800	9 88	5·88	0·88	3·13		44·25	
	Co 331	800	10·00	6·13	0·13	3 75		43·75	
December	Co 210	600	12 33	9 00	0·50	2 33	0 5	57·50	
	Co 213	800	11 38	7·63	1·25	2 50	.	45·50	
	Co 299	800	8·00	6 38	0 13	1·13	0·38	43·63	
	Co 313	800	10·00	6 75	0 75	2 25	..	45·50	
	Co 331	800	9 25	6 75	0·25	1 80		45·38	
January	Co 210	600	7·50	6 50	0·17	0 17	0·67	63·13	
	Co 213	800	8 75	5 50	1·38	0 88	1·00	49·25	
	Co 299	800	6 88	5 75	.	0 63	0·50	48·00	
	Co 313	800	6·00	4·50	0 13	1 13	0·25	49·50	
	Co 331	800	5·63	4 25	0·13	0·50	0·75	51·25	
February	Co 210	600	8 00	7 00	0·17	.	0·83	71·50	
	Co 213	800	7·75	5·25	1·88		0·63	51·50	
	Co 299	800	5 25	4 88	..	..	0 38	50·25	
	Co 313	800	7 38	5 63	1 00		0 75	51·13	
	Co 331	800	7·00	5·75	0·38	0 38 .	0·50	51·25	

TABLE III.

Number of dead hearts during different months in Variety Co. 210

Time of year	Experimental blocks.						Control blocks	
	No. of plants examined	Dead hearts during the month %	Dead hearts caused by top borer %.	Dead hearts caused by stem borer %	Dead hearts caused by root borer %	Dead hearts caused by borers in combination %	Aggregate dead hearts %	Remarks
April	600	5 83	0 17	0 50	5 17		3 63	In the control blocks 800 plants were examined every month
May	600	6 83	1 0	2 33	3 50		8 38	
June	600	10 00	2 0	5·33	2·67		22 75	
July	600	14 50	5 83	2 0	6·67	.	40 75	
August	600	5 33	1 5	0·17	3 67		40 78	
September	No observations taken due to floods.							
October	600	17 83	12 83	1 33	3 5	0 17	44 75	
November	600	14·33	10·50	0·17	3·67	.	49 25	
December	600	12·33	9 00	0·50	2·33	0·50	57 5	
January	600	7·50	6·50	0·17	0·17	0 67	63·13	
February	600	8·00	7·00	0·17	0·83	0·78	71·5	

TABLE IV.

Number of dead hearts during different months in Variety Co. 213

Time of year.	EXPERIMENTAL BLOCKS.						CONTROL BLOCKS	
	No of plants examined	Dead hearts during the month %.	Dead hearts caused by top-borer %.	Dead hearts caused by stem-borer %.	Dead hearts caused by root borer %	Dead hearts caused by borers in combination %.	Aggregate dead hearts %.	Remarks
April	700	6 71	0 57	0 57	5 56		2 85	In the control blocks 800 plants were examined every month
May	800	5 75	0 13	2·75	2 88		6 25	
June	800	11 25	1 63	6 75	2 88		16 38	
July	800	20 38	7 75	2 50	10 13		35 50	
August	800	4 38	1 50		2 88		38 25	
September	No observations taken due to floods							
October	800	17 75	11 25	1 00	5·13	0 38	42 63	
November	800	14·13	7 13	1 13	5 88		45 5	
December	800	11 38	7 63	1 25	2 50		45·50	
January	800	8·75	5 50	1 38	0·88	1 00	49 25	
February	800	7·75	5·25	1·88	.	0·63	51·50	

TABLE V.

Number of dead hearts during different months in Variety Co.

Time of year	Experimental blocks.						Control blocks	
	No. of plants examined.	Dead hearts during the month %	Dead hearts caused by top-borer %	Dead hearts caused by stem-borer %	Dead hearts caused by root borer %	Dead hearts caused by borers in combination %	Aggregate dead hearts %	Remarks
April	633	3 79		0 16	3 63		4 25	In the control blocks 800 plants were examined every month
May	731	4 38	0 55	0 55	3 28		8 50	
June	800	7 25	2 25	2 75	2 25		11 75	
July	800	17 13	9 63	0 85	6 63		33 25	
August	800	4·00	2·13		1 87		35 63	
September	No observations taken due to floods							
October	800	13	9 5	0 75	2 75		41 25	
November	800	14·38	11 38	0 63	2 38	.	43 5	
December	800	8·00	6 38	0 13	1 13	0 38	43 63	
January	800	6 88	5 75		0 63	0·50	48 00	
February	800	5 25	4·88			0·38	50·25	

TABLE VI.

Number of dead hearts during different months in Variety Co 313.

Time of year.	Experimental blocks.						Control blocks	
	No. of plants examined	Dead hearts during the month %.	Dead hearts caused by top-borer %.	Dead hearts caused by stem-borer %.	Dead hearts caused by root-borer %.	Dead hearts caused by borers in combination %.	Aggregate dead hearts %.	Remarks
April	657	4·26		0·46	3·81		4·50	In the control blocks 800 plants were examined every month.
May	800	5·00	0·25	1·50	3·25		5·50	
June	800	5·75	1·25	2·75	1·75		17·50	
July	800	12·25	5·38	0·63	6·25		35·00	
August	800	4·75	2·25	0·13	2·38		39·13	
September	No observations taken due to floods							
October	800	16·63	9·13	2·38	5·00	0·13	39·88	
November	800	9·88	5·88	0·88	3·13		44·25	
December	800	10·00	6·75	0·75	2·25	0·25	45·5	
January	800	6·00	4·50	0·13	1·13	0·25	49·5	
February	800	7·38	5·63	1·00		0·75	51·13	

TABLE VII.

Number of dead hearts during different months in Variety Co 331

Time of year	EXPERIMENTAL BLOCKS: No. of plants examined.	Dead hearts during the month %.	Dead hearts caused by top-borer %.	Dead hearts caused by stem borer %.	Dead hearts caused by root-borer %.	Dead hearts caused by borers in combination %.	CONTROL BLOCKS: Aggregate dead hearts %	Remarks
April	800	6·00	0·25	.	5·75		6·13	In the control blocks 800 plants were examined every month
May	800	5·55		1·63	3·87		8·88	
June	800	10·88	3·38	3·63	3·88		14·38	
July	800	20·38	7·00	1·63	11·75		36·63	
August	800	5·38	0·75	0·13	4·50		39·88	
September	No observations taken due to floods.							
October	800	16·5	10·5	0·88	5·13		42·25	
November	800	10·00	6·13	0·13	3·75		43·75	
December	800	9·25	6·75	0·25	1·80	0·38	45·38	
January	800	5·63	4·25	0·13	0·50	0·75	51·25	
February	800	7·00	5·75	0·38	0·38	0·50	51·25	

L K ANANTHAKRISHNA IYER

DEWAN BAHADUR DR L K ANANTHAKRISHNA IYER

(1861 1937)

Dewan Bahadur Dr Ananthakrishna Iyer was born in 1861 at Lakshminarayanapuram, one of the Brahman villages in Palghat, in the Malabar district of the Madras Presidency Ananthakrishna's father, L N Krishna Iyer, had inherited the traditions of an orthodox and cultured Brahman family, and was himself a Vedic scholar of great local reputation Ananthakrishna Iyer was the eldest son of Krishna Iyer's family of four sons and two daughters Ananthakrishna's educational career was almost synonymous with the development of English education in the district He completed his education up to the Matriculation in the High School at Palghat which was the forerunner of the present Victoria College. After his Matriculation, he proceeded for higher education to the Kerala Vidyasala at Calicut which subsequently assumed the name of the Zamorin's College Ananthakrishna completed his F A Examination here and we find him next as a student of the Madras Christian College In common with many succeeding generations of students from that institution, Ananthakrishna also came under the inspiring influence of the late Dr William Miller, its Principal at the time At the Christian College, he took Natural Science for his main subject, but under the curricula then in force he had also to have a grounding in Psychology, Philosophy and History Ananthakrishna could not, however, take his degree at the end of his course, and not wishing, due to adverse family circumstances at the time, to burden his parents, he joined service in the Revenue Settlement Office at Ootacamund as a clerk in 1888, but left it in 1890 for the more attractive and quieter work of a teacher in his *Alma Mater*, the Victoria College, Palghat Ananthakrishna worked here for a period of seven years, 1890–97, during which he obtained his graduate degree and also the diploma of Licentiate in Teaching

In 1897 the Cochin State, requiring a Science teacher for the Ernakulam College, offered him appointment as an Assistant Master in Science He accepted this appointment and settled in Ernakulam from 1897 onwards For the next 23 years he was an official of the Cochin State.

The first five years of his service in the State contained few events of note In 1902 came the great turning point in his whole career when he was appointed Superintendent of Ethnography, Cochin State, in addition to his full-time substantive appointment as teacher in the Ernakulam College. His career in the Educational service terminated in 1914, when his organizing capacity and scientific training were requisitioned to create the State Museum, the State Zoological Gardens and an Industrial Bureau. When Mr. Ananthakrishna Iyer retired from the Cochin State in 1920 the Government issued

a Gazette Extraordinary referring to his valuable services to the State in the following terms :—

> 'The Government desire to place on record their high appreciation of the valuable services rendered by Mr. Ananthakrishna Iyer during his twenty-three years' service. His work in the field of Indian Ethnology is known throughout India and Europe and has brought honour not only to himself, but also to the State under which he has been employed.'

This was soon followed by the Government of India conferring on him the title of Rao Bahadur in 1921.

Ananthakrishna Iyer's activities as Senior Lecturer in the Department of Anthropology, Calcutta University, and Officer in charge of Ethnography, Mysore, for a period of 17 years after his retirement from Cochin are best examined with reference to his earlier work as Ethnologist in the Cochin State They form in fact a logical continuation of the earlier investigations in the field of Anthropology which he had started in Cochin Soon after the Census of 1901, the late Sir Herbert H. Risley inaugurated a comprehensive Ethnographic Survey of India That programme was not merely confined to British India, but embraced the Indian States as well The Cochin Durbar in response to the request from the Government of India agreed to undertake a survey of its peoples and appointed Ananthakrishna Iyer as Superintendent of Ethnography of the Cochin State This appointment he held from 1902 to 1924, and he carried out his work in that capacity even after his retirement from the State in 1920 The results of his investigations were published from time to time in the form of brief monographs on each caste or tribe which were later incorporated in his work on *Cochin Tribes and Castes* published in two volumes (1908–1912).

The publication of these two volumes evoked considerable interest in the anthropological world Dr John Beddoe, who contributed the preface to the first volume, testified to 'the importance and interest and to the great desirability of its being read and pondered by students of Ethnology and Sociology in England and the West generally'. The late A. H Keane who had invited special attention in *Man* for March 1907 to the earlier monographs by 'this enthusiastic student of primitive peoples' contributed an introduction to this volume.

By 1913, that is after the publication of the two volumes of *Cochin Tribes and Castes*, Ananthakrishna Iyer's reputation as an anthropologist was established We find him elected President of Anthropology in the foundation session of the Indian Science Congress at Calcutta in 1914, with the late Sir Ashutosh Mookerjee as General President. In 1916, the University of Madras appointed him Reader in Indian Ethnology to deliver ten lectures

During the eight years from 1912–1920, Ananthakrishna Iyer was engaged in further studies on the peoples of Cochin. The original plan was to complete the Cochin survey in three volumes, the last one being devoted to an

Anthropometric enquiry This was interrupted by an independent enquiry on the Syrian Christians of Malabar, Cochin and Travancore. The monograph bearing the same name was published by the Cochin Government Press in 1924, after Ananthakrishna Iyer's retirement from the State

In 1920, the University of Calcutta invited him to deliver a course of University Readership lectures in Anthropology, after which he was appointed as lecturer in Anthropology in the Calcutta University Ananthakrishna Iyer joined the Calcutta University early in 1921. He remained the head of the Department and the Chairman of the Board for Anthropology till his retirement in 1932. In 1924 he was appointed to complete the Ethnographic Survey of Mysore, started by the late Dewan Bahadur H V Nanjundaiya Ananthakrishna Iyer assumed charge of the survey in 1924, and from that year onwards during every vacation after the University sessions at Calcutta, he proceeded to Mysore and toured the villages to collect information for the Ethnographic Survey The entire work was completed by 1936 with the publication of four volumes and a final volume of appendix

After Ananthakrishna Iyer's retirement from the Calcutta University in 1932, he still continued as Officer in charge of Ethnographic Survey for Mysore which, in fact, terminated only with his final departure from our midst.

Early in 1934, Ananthakrishna Iyer received invitations to lecture at a number of Universities in Europe He had never been out of India before, and in spite of his advanced age—he was seventy-two at the time—and his strict vegetarian habits of food, he decided to proceed on a voyage . a fact which speaks volumes for his courage and adaptability He had his youngest son, Mr L. A. Natesan, to assist him He sailed on April 23, 1934, and spent about five months out of India Disembarking at Brindisi, he proceeded to Naples and thence to Rome He addressed the Department of Indian Culture of the Royal University of Rome on 'Black Magic in India'. Visiting Florence on May 14th, he spoke at the Institute of Anthropology of the University of Florence on 'Primitive culture in Southern India'. The Rector of the University presented him with the University Medal as a token of appreciation of his scholarship and contributions to Anthropology. Towards the end of May he arrived at Paris and spoke at the Anthropological Institute and the School of Indology under the late Dr Sylvain Levy Early in June he gave a lecture on South Indian Culture at the Pitt-Rivers Museum at Oxford before an audience no less distinguished. He next started on his lecture tour in Austria and Germany. At Vienna he addressed the Asiatic Society and the Anthropological Society. He next visited in succession Breslau, Berlin, Königsberg, Halle, München, Heidelberg, Bonn and Cologne. He gave lectures at the Universities and Anthropological Societies in all these famous centres of European learning, except at München and Heidelberg Most of his lectures were illustrated with lantern slides and greatly appreciated The visit to Germany lasted only till July 14, 1934, as it had to be cut short on account of the approaching International Congress of Anthropological and Ethnological

Sciences at London. One of Ananthakrishna Iyer's objects in going to Europe was to attend the Congress, which was the first International gathering of its kind and which was due to open on July 30th His long record of contributions to Anthropology and Ethnology was recognized by the Comite d'Organization, and he was elected unanimously to the Comite D'Honneur of the Congress. Ananthakrishna Iyer took a prominent part in the proceedings Besides reading a paper entitled 'The Agricultural Basis of Religion in India' he also served as Vice-President of the sections of General Ethnology and Sociology. Soon after the session was over, Ananthakrishna Iyer embarked at Venice and arrived in India towards the end of August, 1934

Ananthakrishna Iyer's activities thereafter were directed to two tasks. He prepared an index and appendix volume to the *Mysore Tribes and Castes.* When this was done—it was only a matter of a few months—he desired to take up seriously the ethnographic survey of Coorg, which he used to say was the only blank in the present literature on South Indian Ethnography With his accustomed enthusiasm and energy, he conducted this survey during the cold weather of 1934 and the summer of 1935 with Professor Lidio Cipriani, whom he had invited from the University of Florence, as a collaborator His manuscripts were almost ready for the press by February last when he was cut off unexpectedly and without warning from his labour of love

In 1935, evidence came forth of a further recognition of his work as a scientist. The President of France honoured him by electing him to the distinction of the Officer D'Academie The Government of India conferred on him the title of Dewan Bahadur The University of Breslau awarded him the Honorary Doctorate of Medicine and Surgery (the Faculties of Medicine control the Department of Anthropology and Ethnology in the continental universities)

His connection with scientific institutions afford some light as to the scientific contacts he developed and cultivated He was one of the original members of the Indian Science Congress, and had attended, except for a year or two, all its annual sessions He was five times President for Anthropology in the Indian Science Congress, and would have celebrated, if only he had lived for another year more, his Jubilee participation in the Congress He was once President for Anthropology in the Oriental Conference, Corresponding member of the Anthropological Society, Bombay, Associate Member of the Asiatic Society of Bengal, Calcutta; Member of the Mythic Society, Bangalore, Foundation Fellow of the Indian Academy of Sciences, Foundation Fellow of the National Institute of Sciences, Corresponding Member of the Royal Anthropological Institute of Great Britain and Ireland, Corresponding Member of the Bureau of American Ethnology, Washington; Member of the Intermediare Sociologique, Bruxelles; Honorary Fellow of the Anthropological Societies of Firenze, Vienna and Koln, Fellow of the Asiatic Society, Vienna, Member of the Eugenic Society, London. More recently, in December last, the Scottish Anthropological Society elected him Honorary Member, as a token of

appreciation of his contributions to Anthropology On February 13, the old Berliner Gesellschaft fur Anthropologie, Ethnologie und Urgeschichte elected him Honorary Member but before the communication could reach the hands of Dr Ananthakrishna Iyer he had passed away

Dewan Bahadur Dr. Ananthakrishna Iyer was known to a wide circle of friends as a man of genial temperament and unfailing courtesy He was simple in his habits and throughout led the life of an orthodox South Indian Brahman, doing his *Pujas* regularly every morning

Dr Iyer leaves behind him to mourn his loss Mrs. Iyer, who was a source of inspiration and encouragement to him for forty-five years, four sons and four daughters, all of them happily settled in life His eldest son Mr L A Krishnan is an Anthropologist in Travancore, the second is Dr L A Narayanan of the Geological Survey of India, the third is Dr L A. Ramdas of the Indian Meteorological Service, and the youngest is Prof L A Natesan, Professor of Economics in the Scottish Churches College, Calcutta

Bibliography of Principal Works

A complete list of the works of Dewan Bahadur Dr L K Ananthakrishna Iyer will have to include scores of short papers, communications, reviews and articles which he had contributed to various learned societies, papers and journals The numerous papers he had read before the Indian Science Congress and the Presidential Addresses will be found in the records of the Royal Asiatic Society, Calcutta, but his principal works on Indian Ethnology, on which his claim for reputation as an anthropologist rests, are given below —

1. The Cochin Tribes and Castes, Vol I—Cochin Government Press, Ernakulam, 1908 , pp 366, 44 photographs.
2. The Cochin Tribes and Castes, Vol II—Cochin Government Press, Ernakulam, 1912 , pp. 504, 81 photographs.
3. Ethnology of South India, a contribution to the Encyclopædia of South India, 1920
4. Syrian Christians of Malabar, Cochin and Travancore—Cochin Government Press, 1924 , pp 340, 44 photographs.
5. Lectures on Ethnography—Calcutta University Press, 1926 , pp. 277, 44 photographs
6. Mysore Tribes and Castes, Vol I—Mysore Government Press, 1935 , pp 550, 60 photographs
7. Mysore Tribes and Castes, Vol II—Mysore Government Press, 1928 , pp. 578, 78 photographs.
8. Mysore Tribes and Castes, Vol III—Mysore Government Press, 1930 , pp. 615, 75 photographs.
9. Mysore Tribes and Castes, Vol. IV—Mysore Government Press, 1931 ; pp. 550, 75 photographs.

10. Mysore Tribes and Castes, Appendix ; pp. 70.
11. Notes on Ethnography, Calcutta University Press.
12. Ethnography of Coorg—awaiting publication.

L. A. K I

ALBERT HEIM

PROFESSOR ALBERT HEIM

(1849-1937)

Prof. Dr. Albert Heim, the nestor of European geologists and author of the celebrated classic 'Geologie der Schweiz', passed away at Zürich on the 31st August, 1937 at the ripe age of 88½ years.

Born at Zürich in 1849, his life's work, the geology of Switzerland, and the unravelling of the complexities of Alpine folding, from an early age was done under the auspices of the University of Zürich, as student, teacher, professor, field investigator, and interpreter of Alpine tectonics. His interest in geology began at an early age when, as a student of Prof. Escher von der Linth, he studied the Glarus 'double fold' in the High Calcareous Alps, a subject of long-standing controversy among Swiss, French and German geologists. He succeeded to the chair of geology at the Polytechnic in Zürich in 1873 at the early age of 24 and in the following year to that at the University of Zürich. Both these chairs he occupied with great distinction till 1911, producing during the interval a number of important works, including his famous 'Mechanismus der Gebirgbildung' in 1878, the 'Handbuch der Gletscherkunde' in 1885, the 'Geology of the Alps' in 1891, besides several folios of the geological map of Switzerland. It was not, however, till 1922, 11 years after his retirement from active duties at the University, that the monumental 'Geologie der Schweiz', the 'finest national text-book that is ever likely to be written' was published. On this work of 1,700 pages Heim had spent 15 years of devoted labour, largely in preparing the 325 illustrations, the copper-plates of many of which he had himself engraved and the 55 plates of maps and profile drawings, all of which attest to his high artistic skill. His drawings and panoramas of typical sections of the Alps, besides being of high value as tectonic interpretations, are works of art. Heim also was a great modeller and the beautiful series of relief models in plaster of some key-areas of the Alps which adorn the Geology Museum at the Zürich University were executed by him personally, or under his direct supervision, after years of patient measurement and modelling. From 1894 to 1925 Albert Heim was Director of the Swiss Geological Commission. In collaboration with Carl Schmidt he published in 1894 the valuable geological map of Switzerland on the scale of 1 : 500,000, the second and revised edition of which he lived to publish thirty-three years later.

To the present generation of Swiss geologists Albert Heim was like a father, venerated by them alike for his great scientific achievements as for his ideal life and character. Dr. Heim was honoured by many Universities, Swiss as well as foreign, and the Royal Society of London elected him a Foreign Member. He was associated in a like capacity with many Geological,

Geographical and Natural Science Societies of Europe. Dr. Heim was elected Honorary Fellow of the National Institute of Sciences of India in 1936. He leaves behind him his son, Dr Arnold Heim, himself a distinguished geologist, whose investigations in different parts of the world as well as whose collaboration with his father during the latter part of his life are well known

D. N. W.

LORD RUTHERFORD OF NELSON

(1871-1937)

The Rt Hon Lord Rutherford of Nelson, O M, F R S, D Sc LL D, etc, Cavendish Professor of Experimental Physics and Director, Cavendish Laboratory, Cambridge, was elected an Honorary Fellow of the National Institute in 1935.

Ernest Rutherford was born of middle-class parents at Nelson, New Zealand, on the 30th of August 1871 He was educated at Nelson and Canterbury Colleges of the University of New Zealand His University career was very brilliant, and after graduation he started researches on his own initiative in New Zealand on the effect of high frequency discharge on the magnetism of iron, which led to his discovery of the magnetic detector of Hertzian waves He came to England for further studies and passed the M A Examination of the Cambridge University with first-class honours in Mathematics and Physics in 1893. At the recommendation of the University of New Zealand he was awarded in 1894 an Overseas scholarship by the Royal Commissioners for the Exhibition of 1851, and he prosecuted researches at the Cavendish Laboratory, Cambridge, under Prof Sir J J. Thomson till his appointment as the Macdonald Professor of Physics at the McGill University, Montreal, Canada, in 1898, which post he held till 1907 when he was appointed Langworthy Professor and Director, Physical Laboratory, University of Manchester In 1919 he was selected to succeed his old teacher Sir J J Thomson as the Cavendish Professor of Experimental Physics at Cambridge, and was elected a Fellow of Trinity College During all these years he carried out fundamental researches on X-rays and ionization of gases, on radioactivity, which led in co-operation with Profr Soddy to the theory of successive and spontaneous disintegration of elements On his return to England, he took up the subject of the structure of the atom which results in the nuclear theory of the atom now considered as the foundation of atomic physics At Cambridge he concentrated his attention on the nucleus of the atom, and it is due to his great organising ability and experimental skill that the Cambridge School was able to make such fundamental contributions as the discovery of the neutron—practical methods for transmutation of elements These works naturally brought him recognition from the whole world—several Universities of Europe and America vied with each other in conferring on him their highest academic distinctions He was elected a Fellow of the Royal Society of London (1903), awarded the Rumford Medal (1905), the Bressa Prize of the Turin Academy of Sciences (1908), Nobel Prize for Chemistry (1908), Barnard Medal (1910), Copley Medal (1924), Albert Medal (1928) and Faraday Medal (1930) He was knighted in 1914 and in 1932 was made a Peer of the Realm

Rutherford was elected President of the British Association for the Advancement of Science in 1923 and was President of the Royal Society of London from 1925 to 1930. He was to have presided over the Joint Session of the Indian Science Congress Association and the British Association for the Advancement of Science in 1938, and had already prepared a very learned and inspiring address for this occasion when, following an operation for hernia, he suddenly died in October 1937. In his Presidential Address to the Science Congress he gave a brief summary of his work in connection with the transmutation of matter.

As Niels Bohr, the famous Danish Physicist and a former pupil, speaking of Rutherford's work at Bologna, said, 'His achievements are so great that at a gathering of physicists like the one here assembled, they provide the background of almost every word that is spoken'

Lord Rutherford had a charming personality and used his colossal energies and tireless enthusiasm in the service of Science He has been described as the 'Prince of Experimenters', and Sir James Jeans rightly remarked 'He has been cut off in the fulness of his powers—leaving as his monument a rich and full life's work, such as few men have equalled, but also leaving a feeling that he might have accomplished more, and possibly even greater, things had he been left with us a few years longer'

B. P.

CALCUTTA:—Published by the National Institute of Sciences of India, 1, Park Street, and Printed by P Knight, Baptist Mission Press, 41A, Lower Circular Road

9-8-38

Symposium on the Malaria Problem in India.

Malaria is not only a disease of major public health importance in India, but it is also one that presents innumerable problems of local and scientific interest for investigation and research. The entomologist, the protozoologist, the pharmacologist, the sanitarian and the public health engineer are all interested in one or other of its diverse problems and specialists all over India are studying these with a view to elucidating them. It was, therefore, considered desirable to collect together workers representing the various specializations from different parts of the country and to afford them an opportunity to present their researches and the special problems encountered by them, so as to elicit a discussion that would be helpful and profitable to the country in general and to the malariologists in particular. The National Institute of Sciences of India undertook to organize such a symposium in Calcutta and appointed Dr R. B. Lal to be the Convener. Reputed malariologists from different parts of India were invited to attend the symposium. Thanks to the ready response of the workers and their employers there was a good and representative gathering. The meetings were held for two days on the 27th and 28th August, 1937, at the All-India Institute of Hygiene and Public Health, Calcutta, under the joint presidency of Prof. M. N. Saha, F.R.S., and Col. R. N. Chopra, C.I.E., I.M.S., on the first and of Sir U. N. Brahmachari on the second day. In all 28 papers were read.[1] They may be classified under the following heads :—

(I) Treatment, (II) Epidemiology, (III) Irrigation and Malaria, (IV) Immunity, (V) Control, (VI) Malarial Engineering, (VII) Entomology, (VIII) Protozoology, (IX) Ichthyology.

I.

1. Col. Chopra opened the session by discussing the relative value of various anti-malarial drugs such as cinchona alkaloids and the new synthetics employed for the treatment and prevention of malaria. He drew special attention to a new German synthetic drug cilionol which, though still in the experimental stage, promises to become a very useful addition to the drugs already in use, because of the fact that it can be safely used for mass treatment.

In connection with Col. Chopra's paper Dr. P. Neogi (Calcutta) said that before the introduction of cinchona preparations in India several vegetable drugs containing bitter principles were being used very extensively for counteracting malaria. The Indian *Kaviraj* professes to cure malaria and other

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[1] For a list of the papers, see pp. 142, 143.

kinds of fever with pills containing these. He asked Col. Chopra if he had investigated the composition of any of these pills and the nature of the bitter principles in them. If not, he suggested that they may be investigated as he believed that they certainly possessed anti-malarial properties

The synthetic anti-malarials possessed distinct advantage over quinine and other alkaloids inasmuch as the latter produced cinchonism, in some persons, even in medicinal doses.

2. Dr. K. V. Krishnan (Calcutta) said that his detailed investigations on the biochemical changes taking place in the blood of hæmoglobinuric and non-hæmoglobinuric monkeys during the different stages of the disease, with special reference to those chemical constituents that were known to be associated with the phenomenon of hæmolysis, such as cholesterol, inorganic and organic phosphorus and glucose had brought out the fact that in the pre-hæmoglobinuric stage the following changes were conspicuous: (*a*) a fall in glucose and a rise in inorganic phosphorus; (*b*) a rise in cholesterol esters, and a fall in total cholesterol in a fair number of cases and a marked fall in free cholesterol in all cases; and (*c*) a rise in organic phosphorus. Somewhat similar results were also obtained in human cases of blackwater fever. From these findings it was concluded that the phenomenon of hæmoglobinuria both in man and in monkeys was determined by the manner in which the host reacted to the stimulus of malarial infection. The production of the hæmolytic agent, as well as the conditions that favour its action, seem to be the result of altered metabolism due principally to liver injury. Whatever the true nature of the hæmolysin may be, it is clear that its action is definitely inhibited by excess of *free cholesterol.* So in the treatment and prevention of blackwater fever the aim should be: (1) to prevent liver injury, (2) to correct the consequent alterations in fat metabolism; (3) to stimulate the cholesterologenetic centres in a manner such that the synthesis and mobilization of free cholesterol will keep pace with the increased demand; and (4) to stimulate the reticulo-endothelial system so that phagocytosis and the cholesterol stores of the body may be maintained. Preliminary studies showed that all these could be accomplished to a certain extent by injections of glucose, ascorbic acid and cortin.

In connection with Dr. K. V. Krishnan's paper Dr. S. C. Seal wished to be enlightened on the following points:—

(1) What was the effect of the injection of 'cortin' and ascorbic acid on the free cholesterol content in monkeys suffering from hæmoglobinuria? Was it definitely increased?

(2) Has any attempt been made to burn out or prevent relative or actual increase of ester-cholesterol which is directly or indirectly associated with the production of hæmolysis by any process?

Dr. Krishnan replying said that there was a definite indication of the ratio between free and ester-cholesterol being brought back to normal after the use

of cortin and ascorbic acid. Regarding the other question he said that he had tried substances like glutathione for the purpose but had failed to obtain any beneficial results.

Mr. N. N. K Iyengar said that Dr Krishnan had tried the injection of choline hydrochloride without success in the treatment of blackwater fever. Recent experiments showed that choline was first decomposed to betaine which prevented storage of fat. It was likely that this decomposition to betaine was rendered difficult in cases of blackwater fever He suggested direct feeding of betaine in small quantities in cases of blackwater fever.

Dr Krishnan replied that he was aware about the decomposition of choline to betaine and that he had also tried betaine but without success He, however, had obtained good results by the use of a combination of choline hydrochloride and quinine in the treatment of monkey hæmoglobinuria. Thus the suggestion that the mechanism of conversion of choline to betaine was at fault was untenable.

3. Dr. Dikshit being absent his paper was taken as read The main points of his paper may be summarized as follows —

His experimental observations show that plasmoquine is liable to affect most systems of the body especially the cardio-vascular and the digestive systems Cardiac irregularities are produced by intravenous injection of the drug and therefore this method of administration should be avoided. The liver seems to be the organ which is very often affected by toxic symptoms seen after clinical use of the drug. The action on the reproductive system, however, does not appear to be harmful, and there is some evidence to believe that even large doses fail to interrupt the course of a normal pregnancy. The fact that a combination of quinine and plasmoquine antagonizes the stimulant effect of both on the isolated uterus is interesting from a clinical point of view for such a combination has proved useful in the treatment of malaria.

(1) Toxicity tests on protozoa and bacteria show that plasmoquine is not toxic.

(2) Plasmoquine has no antipyretic action of its own, but in combination with quinine it lowers temperature quicker than quinine alone.

(3) The cardio-vascular system is depressed by small doses of plasmoquine Larger doses produce cardiac irregularity.

(4) The gastro-intestinal motility is depressed and toxic doses produce fatty degeneration of the liver.

(5) The contractions of the isolated human or animal uterus are increased by low concentrations of plasmoquine and decreased by high concentrations.

(6) Contractions of the intact animal uterus are not affected by administration of therapeutic doses of plasmoquine given over a period of five days.

(7) Therapeutic or even toxic doses of plasmoquine given to pregnant guinea-pigs do not produce abortion.

4 Col Chopra said that he had treated six patients of neurosyphilis by parenteral administration of *P knowlesi* Although no beneficial effect was noted on the patients' nerve condition, he arrived at the following conclusions —

(a) The monkey malaria parasite can be safely given to human beings
(b) They are particularly suitable for the treatment of aged and debilitated cases
(c) As monkeys do not suffer from syphilis there is no risk of giving this infection to man by using their blood
(d) These parasites can be maintained in the laboratory with great ease
(e) The infection in humans has a tendency to spontaneous recovery
(f) Sometimes when after infection the fever is high it can be controlled easily by atebrin or quinine

II

5 Dr R B Lal (Calcutta) gave an account of the methods of forecasting malaria which had been in use for over 16 years in the Punjab He discussed the principles underlying the methods of forecasting and invited discussion as to whether those methods could not be profitably developed to suit the varying conditions in different provinces of India If this could be done the administrative officers, being forewarned could concentrate their attention to specific areas where epidemics of malaria were likely to develop in particular years He then discussed the following factors actually made use of in Gill s method of forecast for the Punjab —

(a) The spleen rate of school children taken all over the province in the month of June
(b) The rainfall figures to obtain an idea of the strength of the monsoon
(c) Economic condition
(d) Epidemic figure for each *thana* or town obtained by dividing the fever mortality for October by the average fever mortality for the months of April, May June and July
(e) The epidemic potential factor or the coefficient of variation of malaria deaths
(f) The co efficient of correlation between rainfall and fever deaths for the month of October for the district

In connection with Dr R B Lal s paper Mr Senior White stated that Punjab had given a 16 years' lead to other provinces in this respect Fore casting in his opinion had been of great value He could not understand why the other provinces did not adopt it Will not the staff of the Malarial Survey do it for the provinces subject to epidemics ?

Prof J N Mukherjee (Calcutta) asked how far the forecasts agreed with the actual incidence of epidemics in each district

The President enquired if the periodical epidemics showed any correspondence with the sun-spots

In his reply Dr Lal said that while there was a fair amount of agreement between the forecast and the actual happenings, he believed that the method in use at present was capable of improvement to a considerable extent His main difficulty was with regard to the assumption that the autumnal deaths were necessarily due to malaria because he was not convinced that sufficient evidence in support of that assumption had ever been set out

The sun-spot cycles exhibited 11 years' periodicity Sixteen years, during which the subject had been studied, was too short a period for studying the correspondence between sun-spot cycle and periodicity of malaria incidence However, a correspondence between the two events might be expected because malaria epidemics in the Punjab were markedly influenced by the amount of rainfall which in turn had been correlated with sun-spot cycles

6 Dr A C Banerjea (Lucknow) discussed the essential factors responsible for urban malaria in the United Provinces He classified them as follows :—

1. *Natural causes* :
   (a) Due to urban areas growing in the midst of malarious zones as in the Tarai and foot-hill regions
   (b) Due to drying up of rivers on which cities are situated or due to change in the course of rivers

2. *Man-made malaria*
   (a) Due to proximity to irrigation canals and wet crops, viz sugar-cane and rice
   (b) Due to defective railway systems interfering with natural drainage or creating fresh breeding grounds, viz burrow-pits, excavations, etc
   (c) Due to ill-developed cities
   (d) Due to breeding in wells
   (e) Due to proximity to big lime and brick kilns and excavations
   (f) Due to lack of co-ordination between different bodies responsible for urban sanitation.
   (g) Due to domestic causes
   (h) Due to ill-developed industrial centres in urban areas

He further stated that urban malaria in the United Provinces was mostly endemic and periodical fulminant epidemics like those in the Punjab were practically unknown. The two seasonal rises were in spring and autumn. One was due to benign tertian infection and the other to malignant tertian infection. The principal carrier mosquitoes incriminated were *A. culicifacies* and *A. stephensi*

Urban malaria to a very large extent was man-made and could be reduced by sound sanitation, by co-ordinated activities on the part of the different

departments concerned and by enforcement of suitable anti-malarial bye-laws. In a campaign against urban malaria, the investigation and anti-malarial measures should not only be confined to the area itself but to at least one mile area all round the territorial limits of the urban areas.

In connection with Dr. A. C. Banerjea's paper Mr. Senior-White (Calcutta) enquired what the writer meant by the term 'incriminated'. No records of *A. culicifacies* having been found infected in the areas investigated by Dr. Banerjea were known to him. If Dr. Banerjea found the species infected this information has not been published.

Dr. Banerjea replied that the term 'incriminated' was used because the insect was found infected on dissection. This information had been recorded in his reports.

Referring to the breeding of mosquitoes in connection with sugar-cane cultivation Dr. Ananthasamy Rao enquired whether the carrier species were bred in the irrigation channels or in the actual cane plots He also sought information regarding the system of irrigation adopted and enquired whether it was continuous or intermittent

7. Mr. M O. T. Iyengar (Calcutta) said that many species of Anopheles were specialized in regard to their breeding habitats and were adapted to breed in certain types of breeding places Their distribution would, therefore, be determined by the availability of the type of breeding place suitable for the particular species. Consequently, in a country with different topographical regions, the anopheline fauna shows considerable variation. The species responsible for the transmission of malaria would also differ in the respective regions and the problems connected with the control of malaria would therefore differ with the areas concerned.

The province of Bengal, which extends from the Himalayas to the sea, includes different types of country: the mountains, the foot-hill region, the dry undulating area, the deltaic area and the mangrove area.

Studies in these regions have brought out the interesting fact that the operations of man have increased the facilities for the breeding of the harmful species of *Anopheles*. In the virgin state, it is probable that the incidence of malaria was comparatively low. In many of the regions, the high incidence of malaria is largely the result of human operations. The occurrence of malaria in the submontane regions is probably largely due to the extensive forest clearance operations for the purpose of tea and rice cultivation. The clearance of the forests have eliminated the harmless species of *Anopheles* and have offered facilities for the intensive breeding of the harmful species. In the pastural region with little or no malaria, the localized foci are the results of attempts to alter the natural conditions, as for example, creating terraced plots for rice cultivation, colliery operations, impounding of rivers and the digging of wells for water supply. In the deltaic area, the construction of embankments to prevent the flooding of the land by rivers in flood or by the tides largely contribute to the establishment of endemic conditions. In the

estuarine area, the clearing of the forests and the prevention of tidal flushing are responsible for the establishment of malaria endemicity through intensive breeding of *A ludlowi*. In most of the cases these results are due to interference with natural conditions without due precautions being taken against the natural consequences of such interference.

8. Dr G. C. Chatterjee (Calcutta) said that it was generally accepted that agriculture in a general way would tend to diminish malaria, but that cultivation of rice, to the exclusion of other agricultural products, might increase malaria incidence Therefore, balanced agriculture was a pressing need of the province. The production of fodder crops for feeding cows, which are useful in many other ways, is highly desirable. This will also tend to improve the humus content of the soil on which fertility depends and will lead to improvement of public health Cultivation all the year round will tend to nullify, to a great extent, the scorching effect of the tropical sun. It will also tend to lessen the scouring action of the floods during the rainy season which tend to produce soil erosion. These in turn remove the top dressing of land.

In Bengal, from time immemorial, a system of irrigation of lands around excavated tanks or bunded reservoirs is extensively prevalent. This system is seen in Burdwan, Midnapore, Bankura and other districts, but not to the same extent in districts like Khulna, Jessore, Dacca, where there are a large number of rivers. It is, however, getting out of use, due to the constant migration of the people to towns, and to the tanks becoming the joint property of several members of a family and thereby getting neglected It is, however, still in force in several places and can be made use of for the improvement of agriculture as well as for the prevention of malaria.

Recently a large number of small co-operative irrigation societies have been formed in Bankura and Birbhum districts for utilizing these tanks for irrigation purposes. The system has thus been given a new lease of life If by some means or other, propaganda can be done for enlarging the scope of this scheme lasting good to the country is bound to result Cultivation should include some type or other of fodder plants and leguminous crops The people should be made to understand that milk along with fish is the greatest protective food ; and these should be made available for all at a cheap price. When this is done it will automatically solve the malaria problem of the province

9. Due to the absence of Prof de Mello, his paper was taken as read The points of interest in the paper may be summarized as below :—

The highly malarious regions in Portuguese India are Novas Conquistas in Goa, Pragana in Daman, the town of Diu and certain villages of Brancavara in Diu The three important anopheline carriers of malaria are *A. listoni*, *A culicifacies* and *A stephensi* The chief anti-malarial measure practised is the treatment of infected persons and carriers. Plasmoquine and atebrin have been tried with great benefit. Mass treatment with quinine-plasmoquine

during pre-epidemic periods has given encouraging results. The use of atebrin-musonate in the treatment has proved valuable. In rural areas it has not been possible to conduct any anti-larval campaigns.

III.

10. Dr. Sweet (Bangalore) stated that there were three types of irrigation systems in Mysore State. One type involved a small area under a local tank. It was usually not malarious. A second type covered a larger area under a bigger and more permanent tank. This was frequently malarious. The third type was an extensive riverine system which was invariably malarious. The riverine system not only produced an initial epidemic of malaria at its commencement, as demonstrated by the history of events following the opening of the Irwin Canal system in June, 1932, but also created highly endemic conditions. The three types of irrigation seemed to differ in (1) the length of main and subsidiary channels, (2) the amount of water used, and (3) the season of the year in which water was available. In these three differences, possibilities for the control of malaria exist, especially in the strict control of the amount of water supplied and its use. Lack of drainage is a defect common to all types but, due to expense, it does not seem likely that this aspect of the prevention and control of malaria in new and existing irrigation systems will receive the attention it deserves until the profit motive is largely removed from consideration.

In connection with Dr. Sweet's paper Dr. K V. Krishnan (Calcutta) in endorsing the views expressed by Dr. Sweet on irrigation and malaria referred to his study of a severe outbreak of malaria in Mopad in the Nellore district of the Madras Presidency in 1925, which had arisen as a result of the introduction of irrigation. The Mopad area prior to the introduction of irrigation was a dry tract of country with only about 10 per cent spleen rate. After irrigation was introduced in 1921, the spleen rate rose to over 50 per cent and, on account of the severity of malaria, agriculturists had to abandon their land and leave the area. Investigations showed that the most important factor that contributed towards the increase of malaria was water-logging of the whole area, resulting from the excessive supply of water and poor drainage. The Government was anxious to sell as much water as possible and the ryots wanted all the water they could get for raising at least two crops of rice. He was, therefore, of the opinion that unless water supply is restricted to the actual needs and financial considerations are not over-emphasized, malaria was bound to arise shortly after the introduction of irrigation schemes in dry tracts of country. He wished to emphasize the importance of the views presented by Dr. Sweet and stated that even if proper drainage could not be effected, restriction of the amount of water supplied plus control of the type of crops raised could reduce malaria to a considerable extent. The mere consideration of immediate financial gain appeared to him a short-sighted policy

11. Dr Masillamani (Madras) said that the irrigation systems in the Madras Presidency varied from place to place He classified them as follows —

(a) Canal irrigation
(b) Rain and river-fed irrigation tanks
(c) Irrigation from springs and hill streams.
(d) Lift irrigation from wells in the beds of streams
(e) Irrigation from field wells
(f) Irrigation or watering from pits

In the case of wells, there was a limited supply and no stagnation or continuous flow of water Wells in the beds of streams got flushed out during floods No malaria was associated with this type of irrigation

In the case of pits in casuarina and cocoanut plantations, they were abandoned after the plants grew to a certain height These provided prolific breeding grounds for *A culicifacies*

Part of the foot-hill malaria in the Presidency was due to irrigation from springs and streams In the plains malaria was associated with canal irrigation and tank irrigation though it was not so in every instance The main factors seem to be the ill-kept canals and uncared for field channels In the seepages from the canals, in the burrow-pits by their side and in the grass-grown edges *A culicifacies* find suitable breeding places The field channels rather than the method of irrigation followed or the kind of crop raised are of the greatest importance The water-logging conditions produced outside the fields, as in the case of sugar-cane and paddy cultivation, are also important, but the semi-stagnation of water in the fields themselves is not of much significance except perhaps in the very early stages of cultivation of paddy In dry irrigated areas, it is the seepages from canals and the canals themselves that are responsible more than the field channels.

The many factors associated with irrigation malaria and the precise scope of their influence are not fully known There are several kinds of water sources, the importance or otherwise of which has not yet been scientifically determined There is also the possibility that malaria in irrigated areas is only a passing phenomenon The endemicity in many places is often very low. We are not justified in blaming the engineer for his errors of omission and commission Drainage schemes are usually utopian, larvicide schemes are make-shift arrangements, and abolition of paddy fields and breaching of tanks are merciless steps. Prevention of percolation, regulation of flow, alteration in supply, maintenance of channels—these are methods in which the engineer should be interested and to these attention should be mainly directed

In connection with Dr. S G. Masillamani's paper Dr K. V. Krishnan (Calcutta) said that it was generally believed that irrigation schemes if properly introduced in deltaic areas helped to reduce greatly the incidence of malaria. Dr. Bentley and others were great advocates of this view The increase in

malaria in certain parts of Bengal had been attributed by them to the gradual decadence of the old irrigation system and people here often quote the excellent results obtained through the introduction of irrigation in the Godavery, Krishna and Kavery deltas. He wanted to ask Dr Masillamani whether he had made a comparative study of the influence of irrigation on malaria in deltaic and non-deltaic areas in the Madras Presidency and whether there were any differences, and if so what they were. He also requested Dr. Masillamani to tell him how far his findings corroborated or contradicted Dr Bentley's views with regard to the beneficial results of irrigation in deltaic areas.

IV

12. Dr Krishnan (Calcutta) said that the course of *P knowlesi* infection varied greatly in different species of monkeys Ordinarily in the *Silenus rhesus* it causes an acute fatal infection, while in *S irus* and *S radiatus* it produces a low grade, non-fatal infection From the splenectomy experiments conducted by him the following conclusions were drawn .—

(*a*) In splenectomized animals the differences due to natural species immunity completely vanishes , all three species suffer alike from acute and rapidly fatal infection

(*b*) The natural resistance of monkeys to the human plasmodium is not influenced by splenectomy.

(*c*) If splenectomy is done during the latent period of infection a severe relapse follows

(*d*) Extirpation of the spleens of immune monkeys results in the disappearance of their acquired immunity in all cases. While in the susceptible species acquired immunity was found to be associated with the presence of residual focus of latent infection, in the resistant species (*irus* and *radiatus*) in about 50 per cent of cases, even in the absence of a residual focus of infection a high degree of acquired immunity was found to be present

(*e*) In connection with treatment of malaria in splenectomized animals the following facts were elicited .—

(1) Larger amounts of quinine were required to cause complete disappearance of all parasites from the peripheral blood.

(2) The drug had to be administered for a much longer period.

(3) The cure rate was distinctly less.

(4) The death rate was markedly higher than in non-splenectomized monkeys.

(*f*) When animals are splenectomized prior to infection with *P. knowlesi* the incidence of hæmoglobinuria is greatly increased In 90 to 100 per cent of splenectomized *rhesus* and in about 30 to 50 per cent of splenectomized *irus* and *radiatus* hæmoglobinuria is met with.

(g) Splenectomy failed to alter the course of Leishmania infection in monkeys

From these studies it is concluded that the spleen plays a part of great importance in the resistance and cure of malaria

In connection with Dr Krishnan's paper Mr N. K Iyengar asked if the effect of splenectomy on the buffering capacity of blood had been studied He considered this an important factor in elucidating the mechanism of resistance as it had been established that there was a relation between the buffering capacity and resistance

Dr. Krishnan replied that as far as their studies went there was no evidence to suggest that the buffering capacity of the blood was altered after splenectomy

13 Dr. M. N De (Calcutta) read a paper on the pathology of the malaria spleen. He described the changes which occur in the spleen in acute and in chronic malaria. While in the former the enlargement is entirely due to the extra burden suddenly thrown upon the organ and to the concomitant vascular changes which inevitably follow such increased output of work, in the latter there is less vascularity and more cellular changes with increase in reticular fibres The capsule instead of being thin is thick and the trabiculæ are more numerous and prominent The typical 'ague cake' spleen is only met with in chronic malaria.

V.

14 Major Afridi (Kasauli) said that the chief causes of malaria incidence in Delhi were —

(1) Excessive canal irrigation coupled with interference with natural drainage by railway, road, and canal embankments in the North-Western section.
(2) Annual flooding of the *bela* by the Jumna, leading to (a) heading up of water in the various storm-water drainage channels, and (b) formation of prolific breeding places as the flood recedes
(3) Presence of vast numbers of excavations throughout the area in the form of burrow-pits alongside railways and roads, and pits in brick-fields and quarries in the ridge area.
(4) Presence of miscellaneous breeding places such as temporary water collections around hydrants, ornamental waters, non-mosquito-proof cisterns, wells and underground storm-water drainage system.

The measures enforced during the past year may be considered under two headings: (i) permanent measures, and (ii) temporary measures.

Permanent Measures.—The permanent measures have been instituted with a view to eradicating breeding places caused through faulty storm-water drains, lack of adequate drainage of low-lying tracts and over-irrigation in the area fed by the Western Jumna Canal. These measures can scarcely

be looked upon as specifically anti-malarial in nature but are designed to provide such surroundings for Delhi as could easily be controlled by the anti-malarial staff. In securing this objective the activities of the Anti-Malaria Organization have been intimately linked up with those of the Delhi Improvement Trust and sanitary improvement programmes in general The successful conduct of these measures has been greatly facilitated by the whole-hearted co-operation of the civil and the municipal administrations and of the officers of the Central Public Works Department who have, throughout, placed all possible facilities at their disposal.

Temporary Measures.—These measures were concerned with the organization of the anti-malarial staff of the various municipalities, the provision of oil, paris-green and other larvicides, and the institution of programmes for adequate weeding, minor filling and draining of small temporary collections of water The central organization for the measures was supplied by the Malaria Survey of India and the striking benefit of such a central control was the elimination of much overlapping of work and the baneful effects of the neglect of one sector to the detriment of the adjoining sector The establishments for different areas have been varied to suit the demands imposed by the climatic requirements and the extent of the breeding sources

In addition, as an experimental measure the quarters of certain isolated communities in the Delhi urban area were regularly sprayed with pyrethrum larvicide These measures yielded very encouraging results Similarly the practicability of spraying of paris-green by aircraft was thoroughly tested and the results have already been published (Covell & Afridi, 1937)

In connection with Major Afridi's paper Dr Sweet said that one point which had interested him for some years was the low spleen rates in urban areas. In many city areas very low spleen rates had been reported, e.g. in Bombay, Calcutta, and Bangalore In urban areas such low spleen rates do not mean an absence of a considerable amount of malaria. The factor which is working is possibly one of dilution which was first mentioned by Christophers. In urban areas, with many children, the chances of any single child getting repeated new infections are small and the resultant spleen rate will be low and not at all representative of the actual malaria. The parasite rate in such cases is frequently higher than the spleen rate. A method of spleen examination which might be more representative of actual conditions would be the use of POI spleens as suggested by Dr. Russell. These small spleens well up under the ribs would possibly give figures which would give a more correct idea of the actual amount of malaria in cities

With reference to the point raised by Dr. Sweet, Dr. Row said that he had found, during an epidemic of malaria in Mysore City, against a low spleen rate in the different wards of the city, a high parasite rate ranging from 15 to 25 per cent. After 5 years of anti-malaria work in the city the spleen rates were round about 2 to 3 per cent, while in two wards the parasite rate was still round about 12 to 15 per cent. Would Major Afridi state if

A. stephensi was considered a carrier in Delhi and what percentage of wells bred this species and how the breeding was controlled ?

Mr. Iyengar said that he wished to know if there was any relation between spleen rates and density of population In his experience Bengal towns with a fair density of population had very little malaria He also wished to know if adult catches represented the actual incidence of adult mosquitoes in the area There was usually very great variation in the catches from day to day and from month to month and even when there was intensive mosquito breeding in ponds, the adult catches were often small and did not reflect the extent of breeding He further enquired about the effect of oil containing 2½ per cent cresol on fish and vegetation Did the water get discoloured as a result of the decomposition of the vegetation ? Did the oil spread equally well in dirty as well as in clean water ?

Dr. Lal enquired whether the question of converting the low-lying *bela* area near Okhla into a lake had been considered. He also wanted to know how they proposed to deal with the Najafgarh Cut which extended to many miles and drained the shallow *jheel* and marshes of Najafgarh By increasing the gradient they will make the level of the outlet lower than that of the river. Did they propose to put in a sump and a lift pump ?

Major Afridi replied to the various points raised in the discussion

15 Dr B A Rao (Mysore) said that one of the objections to the use of paris-green as a larvicide in anti-malaria work was that it was not hundred per cent successful as judged by the standard of larval catches. In the course of field experiments it was seen that the first and second stage larvæ remained almost untouched by paris-green This was perhaps purely a physical defect in that the size of the particles of paris-green in common use was too big for the larva in the early stages of its growth This handicap can effectively be controlled by spraying paris-green mixture once a week, or oftener if necessary, so as to catch these larvæ before they pupate

In the light of his studies, conducted over a period of eight years in the Nagenhalli area, it was possible to conclude :—

(1) That paris-green can be used effectively for controlling anopheline breeding in irrigation channels.

(2) That a one per cent mixture with a suitable inert diluent is quite an adequate strength for use as a larvicide.

In connection with Dr B. A. Rao's paper Dr Sweet emphasized the utility of paris-green as a larvicide in running water He had used paris-green in irrigation channels for years in Mysore with every evidence of success He could not say that he did not get the larval drift mentioned by Sinton He did get the drift, but it was in large channels only and there he had to use booming and other methods mentioned by Sinton. In the smaller channels paris-green was completely effective as far as could be judged by larval dippings, adult catches and spleen and parasite rates.

16. Captain Sinha (Calcutta) said that the Bengal Public Health Department had carried out an experimental scheme in Memari Police *thana* of Burdwan district to investigate the extent to which malaria incidence could be reduced by mass treatment with plasmochin and quinine without carrying out any anti-mosquito measures.

The experiment lasted for four years from 1933 to 1937. It was observed that the malaria incidence had been reduced by more than 50 per cent, the fever index which was 16·0 in 1933-34 had come down to 4·2 in 1936-37. In the control area the index had gone down from 42·5 to 25·0 in the corresponding years. Spleen index also underwent similar reductions In the experimental area it was reduced from 68·0 in 1933 to 21·4 in 1937, while in the control area it was reduced from 60·5 to 42·9 only The parasite index had also been reduced in the experimental area to one quarter of what it was in 1933.

Several factors which adversely affected the results of the experiment were enumerated by him.

In connection with Captain Sinha's paper Dr. Krishnan said that the question of drug prophylaxis of malaria in rural areas in India was a very important one. Rural India watched the results of the Bengal experiment with great interest. But unfortunately the results did not come up to the expectations of many. As explained by Dr. Sinha, several factors adversely affected the success of the experiment. All that one could say at present was that the results so far obtained were not very significant although they were not altogether disappointing.

17. Dr. K. L. Chowdhury (Calcutta) said that the problem of mosquito control in Calcutta could be considered from two aspects

(A) General problem—pertaining to the Corporation of Calcutta in the—
- (*a*) sewered area,
- (*b*) unsewered area.

(B) Special problems—pertaining to the Government of Bengal and the Local Bodies in the—
- (*a*) salt lakes,
- (*b*) areas adjoining municipalities,
- (*c*) port, railways and docks,
- (*d*) irrigation canals, the New Cut, the Circular and the Belliaghata canals,
- (*e*) maidan, Eden Garden, Government House, jails, etc., and
- (*f*) military areas : Fort, Boydguard lines, etc.

The solution of the problem in Calcutta, he said, resolved into the following measures :—

(*a*) In the sewered area :
- (1) House-inspection.
- (2) Adequate legislation like the Mosquito Ordinance.
- (3) Mosquito proofing of cisterns, oiling the street gullies, etc.

(*b*) In the unsewered areas :

(1) Vigorous anti-mosquito measures in tanks, ponds, lowlands, open drains, etc

(2) House-inspection with the aid of adequate legislation

(*c*) In the Salt Lake areas

(1) Engineering schemes, such as land reclamation, cultivation, fisheries, refuse-dumping along a stretch of one mile along the eastern fringe of the city, etc

(2) Research for chemical treatment of sewage in order to make it unsuitable for breeding *Culex fatigans*

(3) Paris-green treatment and oiling

(4) Amendment of the Calcutta Municipal Act of 1923 in order to enable the Corporation of Calcutta to extend anti-mosquito measures up to a mile beyond its boundaries on all sides

(*d*) In the adjoining Municipalities

(1) Vigorous cleansing and oiling of all surface drains, cess-pits, lowlands, etc, especially during the cold months, viz. November to March

(*e*) In the Port and Dock areas

(1) Regular inspection of all boats, ships, barges, etc, and taking suitable anti-mosquito measures

(2) Suitable legislation

In connection with Dr. K L Chowdhury's paper Mr M O T Iyengar (Calcutta) asked what was the present incidence of *Anopheles stephensi* breeding in cisterns in Central Calcutta. It was about 40 to 60 per cent in 1920 according to his survey made during that year

It was necessary that the area surrounding Calcutta was also controlled as it was frequently said that all the *Culex fatigans* found in Calcutta did not breed within the city but came from outside.

Dr. Lal said that as Chairman of the Sub-Committee appointed by the Anti-mosquito Committee of the Calcutta Corporation he had an opportunity of studying the serious problem of mosquito nuisance in Calcutta Those living in the Ballygunge area and in certain other parts of Calcutta were disturbed in their sleep every night and wondered what the city authorities were doing to exterminate this pest. As a matter of fact the anti-mosquito problem resolved itself into two parts, namely, (1) one involving major engineering schemes and the other measures requiring large funds, and (2) one which could be effectively dealt with by proper organization of available resources. It is surprising how much could be done to reduce the mosquito nuisance in this city by the proper handling of the problem Under the present arrangements too much attention was being paid to such breeding grounds as house-cisterns which contributed a comparatively small amount

to the mosquito population but consumed large funds and even so only a few of these could be dealt with.

18. Dr. G. C. Chatterjee (Calcutta) gave an account of the different species of larvivorous fish found in Bengal and referred in particular to the following: (1) *Colisa speciosa* (*Chuno kolisa*), (2) *Haplochilus*, (3) *Panchax panchax*, (4) *Barbus ticto*, *B sophore*, *B conchonius*, *B. stigma*, *B. phutunio*, (5) *Esomus danricus*, (6) *Rasbora daniconius*, (7) *Amblypharyngodon mola*, (8) *Brachydanio rerio*.

He then referred to the larvivorous qualities of the fry of carps and their value in controlling mosquito larval breeding in the tanks of Bengal. In order to encourage the growth and multiplication of larvivorous fish generally, in the tanks, he recommended the cultivation of the land around the tanks enriched as much as possible by the sludge removed from the tanks. If in addition the rain water from these lands is made to drain into the tank then the fish multiply in large numbers and larval breeding is kept down to a minimum

In connection with Dr G. C Chatterjee's paper Dr Krishnan said that he had conducted field experiments in some of the Bengal villages on the utility of fish as mosquito larvæ destroyers through a grant from the Indian Research Fund Association in 1934. He was glad to note that Dr. Chatterjee had found the fry of carps extremely valuable. This was entirely in keeping with his own findings and he wished to emphasize the use of fry on a more extended scale for controlling larval breeding This appeared to be a very useful, economical and profitable measure, under the peculiar conditions prevailing in the Bengal villages.

19. Dr Hora (Calcutta) said that in India there was a variety of indigenous larvicidal fish belonging to the family Cyprinodontidæ, which was probably not inferior to *Gambusia*. The latter had been introduced from outside in recent years. He referred to the recent biological work of Fraser on *Panchax lineatus* (C V.) and of Hora and Nair on *P. panchax* (Ham). On the strength of these studies he made a plea for an intensive stimulus to pisciculture in India, as the young of practically all kinds of sluggish-water fish could feed on mosquito larvæ.

In connection with Dr. Hora's paper Dr. K. L. Chowdhury supported the views expressed by Dr Hora regarding the value of larvivorous fish in malaria control.

Nuria danrica was another very good larvicidal fish. This species was found in Assam particularly during the rains.

In Calcutta good results had been obtained by carefully preserving the fish fauna, whatever they might be, and also the natural vegetation growing there.

Dr. B. Rao (Mysore) said that in Bangalore *Gambusia* was used intensively for the control of *A. stephensi* in wells. The fish together with *B. puckelli* and *B. punctatus* had been stocked in step wells in Chitaldroog district for

guinea-worm control It was observed that all the three species thrived quite well in these wells It was a common observation that the fish, no matter what type it was, was useless as a larvicide in the tanks where there was heavy vegetation. Cleaning the tanks of vegetation was in itself effective and in most cases additional stocking with fish was not necessary When dealing with big areas, it was not practicable to keep the tanks clear of vegetation as the growth reappeared quickly and vigorously The same fact had been observed in wells stocked with *Gambusia* whenever the well water was dirty, and in such cases *A stephensi* was commonly found in association with *Gambusia*

Mr M. O T Iyengar said that he was entirely in agreement with Dr Hora regarding the undesirability of introducing foreign fish like *Gambusia* One should be very wary of any such attempts if one were to profit by the experience of other countries *Gambusia* was very predaceous to the young of edible fish and fishermen in Italy and Spain were violently against the introduction of *Gambusia* as it affected fisheries adversely We know that both *Panchax* and *Anopheles* larvæ are often found together That is because the larvæ are afforded protection by the dense aquatic vegetation. The argument that if we clean the vegetation the mosquito larvæ would also disappear was not always true One frequently observed ponds with very little aquatic vegetation and yet breeding *Anopheles* mosquitoes In such cases, the introduction of *Panchax* would be most effective in controlling mosquito breeding

VI

20 Mr. Curry (Calcutta) said that in Bengal, owing to the economic needs of a rapidly increasing population, embankments, to prevent many of its rivers overflowing their banks, had been erected At first the results of such action were very profitable, crops were grown without risk of ruin by flooding, railways, roads, factories, and all other amenities and accompaniments of material and industrial progress were introduced Later, however, the harmful effects of the policy of embankments began to be felt When a river is embanked the silt, which is intended by Nature to be discharged on to the surrounding lands, could not escape from the river channel and was mostly deposited on the bed, thus choking the channel and causing the bed level to rise As the bed level rises the water level also rises and, in consequence, the embankments have also to be raised to keep pace with the rise in the bed and water levels of the river The lowlands remain at the same levels and so unhealthy swamps are formed which cannot be drained and become a menace to public health. The lands, which would normally be revitalized and moistened by river spill, become infertile and the natural system of surface drainage becomes upset. Owing to the rise in the river levels the danger of breaches in the embankments and of disastrous flooding of large areas becomes great.

The contrast between the conditions in East Bengal and Central Bengal is very striking. In the former (except in a few areas where embankments along rivers have been constructed) the countryside is subject to river spill and is fertile and populated by a virile and healthy population

In Central Bengal where the rivers have been embanked, all the harmful effects mentioned above are evident The rural population is declining and has become debilitated by malaria and other diseases, and agricultural prosperity has decreased.

So a beginning was made, in a small way, with flood-flushing schemes in different parts of the province Thus the highly malarial village areas of Pingla, Naraingarh and Kola in the district of Midnapore, covering an area of 8,278 acres including 729 tanks, have been flushed with water from the Cossye and Rupnarain rivers through the Midnapore canal system, free of charge to the villages, during the flood seasons of 1932 to date

The inhabitants there are kept under medical observation by the authorities of the Public Health Department, and the reports show a marked improvement in public health as evidenced by reduced treatment at dispensaries for malaria and other fevers and by a reduced spleen index The results of the introduction, in 1934, of flood water (free of water tax) from the Gobra Nullah on the lands of the villages of Maidyagobindpur, Madapur, Bahadurpore, Sultanpur, and others in the Murshidabad district, were even more striking, for whole village sites which had been abandoned on account of malaria were re-occupied Seven thousand one hundred and twenty acres were flushed and the report shows that in addition to reducing malaria the yield of the *aman* paddy crop was approximately doubled and grubs and insects like white ants were destroyed

Encouraged by the success of the trial measures mentioned above, and acting on the suggestions put forward by the Public Health Department and by the Rural Development Commission of Bengal, an ambitious scheme has been submitted to the Local Government for flushing 3,50,000 acres in the districts of Burdwan, Hooghly and Howrah, between the Damodar and Hooghly rivers, by the flood waters of the Damodar river at a cost of Rs 273 lakhs (=£2,100,000) The salient features of the scheme include a barrage on the river Damodar near Burdwan and a network of distributing channels fitted with regulators, capable of carrying 13,160 cusecs (a discharge equal to the normal flood discharge of the Thames river at Staines), and adequate sluices for the drainage of the excess water into the river Hooghly.

In connection with Mr. Curry's paper Mr P Neogi observed that the districts of Hooghly, Howrah, 24-Parganas and Burdwan were the districts of Bengal which were most affected by malaria and as an inhabitant of the Hooghly district he was glad to note that a scheme of eradicating malaria by flood-flushing had been made at the cost of Rs.273 lakhs for 3,50,000 acres. The cost was not prohibitive as it was realizable. Flood-flushing or 'Bonificazione' had eradicated malaria from Italy and Panama and it should be tried exten-

sively in North and West Bengal East Bengal on account of natural flood-flushing every year was practically free from malaria Railway embankments were necessary evils but they must be provided with a sufficiently large number of culverts for flood-water to pass freely Flood-water will also flush the railway burrow-pits which contained stagnant water practically throughout the year and were, therefore, fruitful and constant breeding places for malaria Irrigation and malaria were almost synonymous terms and it is flood-flushing which could make them opposite terms

21 Mr Griffin (Calcutta) said that among the various ways in which man's interference with nature had caused drainage obstruction, the following might be mentioned —

(1) Encroachments on drainage channels, either by building over them, or too close to them— thereby confining the channel in too small a width

(2) Obstruction of drainage channels by throwing into them rubbish, earth, or filth

(3) By putting fishing weirs across drainage channels and failing to remove them again when the fishing is over

(4) The construction of embankments for roads, railways, or canals, without making sufficient provision for the natural surface drainage

(5) Paddy field terracing

(6) Mining subsidence The results of mining operations in many places have been known to cause the surface of the ground to cave in, with the result that water stagnates in pools and the gradients of surface channels are interfered with.

One of the experimental anti-malarial schemes carried out by the Bengal Public Health Department in 1917 was in connection with the colliery land near Raniganj. Here the land had been tumbled about by mining subsidence, and in one place there was a level swamp The engineering work done consisted of re-grading the natural surface channels, putting in culverts where embankments were obstructing drainage, and in draining the swamp by means of network of sub-drains. These consisted of earthenware pipes, laid open-jointed in a bed of gravel and broken stone There was a main sub-drain, and branch drains in herringbone fashion Of course, careful levels were taken to shew that there would be a proper outlet for the main sub-drain. The drain at its outlet end was about 4 feet below ground, but there was a lower level channel into which it could discharge.

An interesting form of sub-drain was constructed in connection with the anti-malarial scheme at the Meenglas Tea Estate in the Duars. This estate is traversed by a number of streams (*jhoras*), and there is a good natural slope from north to south As the Anophelines were breeding along the edge of the running water, it was decided to put the streams underground by means

of sub-drains. The long distance for transport would have made earthenware pipes expensive, and as plenty of stone was available at the site, it was decided to make the sub-drains of stone. A stone bed was laid to a continuous gradient, side walls of dressed stone were built on it, and big stone slabs laid across the top,—the whole being then filled in with small stones up to the natural bed of the *jhora* The side walls and top stones were laid without mortar so that water might find its way into the drain through the crevices of the stonework One or two length of small drains were done with pipes, so as to make a comparison in cost. The cost of a sub-drain 9" wide and one foot high worked out at -/7/6 per foot.

In the low-lying parts of flat country like the deltaic areas of Bengal water must lodge during the rainy season, and often,—as far as malaria is concerned,—it is found better not to attempt drainage, but to bring in river water so as to *raise* the general level and thereby reduce the amount of edge round which the mosquitoes breed, hence the ' flood-flush ' drainage schemes Good results have been obtained by the application of this principle In urban areas, where the surface water must be removed from the vicinity of habitations, underground sewerage systems are constructed These, with their pumping stations are, of course, expensive When cheap electric power is available, as in the Calcutta area, neither the capital nor running cost is high A low level tank can be constructed or an existing tank or series of tanks can be made use of to act as a storage reservoir to receive the water from the land to be drained, and by means of a pump of moderate size and cost, the water can be pumped away at leisure. An example of this can be seen at the Jodhpur golf course, where a 4 horse-power pump deals satisfactorily with an area of 80 acres The power required for the pump is so small because the height through which the water is lifted is only six feet

In a deltaic area, the land near the river bank is above flood level, while further away from the river it is below flood level. It follows that there is a natural line,—roughly parallel with the river, and at a certain distance from it, such that, between the line and the river the policy of land raising and natural surface drainage should be pursued

In connection with Mr. Griffin's paper Dr. Lal enquired if mole drainage had beed tried in Bengal

Mr Griffin in his reply said that mole drainage had, so far as he was aware, not been tried in Bengal and he did not think conditions were suitable for it in this province

VII.

22. Mr. Senior-White (Calcutta) said that he had been studying the rôle of various chemical factors such as *p*H dissolved oxygen, mineral solutes and saline ammonia in connection with mosquito ecology He had found that high dissolved oxygen content appeared to favour the use of natural waters by Anophelines, and that this was especially important in rice fields ;

but the principal discovery made was that *saline ammonia in amounts of less than 1 p p.m was inhibitory to natural water breeders*, especially Anophelines On a previous occasion he had studied in addition to pH the following factors and had shown that they were of value in controlling mosquito breeding conductivity, carbonates and albuminoid ammonia He, therefore, recommended further studies on residual pH and dissolved oxygen in the hope that they will yield results of great value Phosphates appeared to be of much less importance than they were when found in sea water they were also worthy of further study The conclusions formerly arrived at with regard to saline ammonia were confirmed for three vector species but not for the non-carrier *A subpictus*. His work had since been confirmed by Beattie (1932)[1] for a Neotropical species, showing that this criterion was the only one of importance so far discovered Whether it was applicable to all the *130* known species of the genus Anopheles was, however, quite another matter

Mr Senior-White also tested the 'herbage cover' method of mosquito control. He had recently found that it had great possibilities It is a recognized method for producing excess albuminoid nitrogen in the presence of deficient oxygenation. It has long been apparent to all workers that chemical larvicides have a very limited application owing to their excessive cost, and are, in fact, quite unsuited to the vast rural tracts of this and other tropical countries Cheaper methods will have to be evolved if anything is to be done for rural malaria generally We now see that in adopting the above methods of malaria control we would be enriching the soil for agricultural purposes as well and this would doubly benefit the villager We come to purely agricultural methods as our main weapon of attack, the raising of fodder crops, the stabulation of cattle, the conservation of cow-dung for manure instead of its wasteful expenditure as fuel. These are questions for the agriculturist and the economist rather than for the malariologist, who can only strengthen the hands of these professions by pointing out that the success in their immediate object will, in time, lead to the control of the 'King of Tropical Diseases'

23 Dr. Sen (Calcutta) stated that *A ludlowi* was migrating more and more towards human habitations year after year This migration is helped in many places through the agency of transport either by train, country-boat, or perhaps by bus This has been shown from the catches made at the different railway stations such as Majherhat, Sealdah, Shambazar and Howrah from time to time, as also from the lock-gates at Baghbazar and Kulti Once transported near human habitations the species takes to new environments and establishes itself. Its great adaptability to various ranges of salinity, even to fresh water, enables it to do so Thus in recent years the species, although normally a brackish-water breeder, has established itself in many places in what may be considered as fresh-water breeding places. This is in

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[1] Buxton's (1934) analysis of this author's findings should be studied *pari passu* with the original paper.

conformity with the experience of workers in estuarine and deltaic faunas. Other factors which help the spread of this species are heavy rainfall and embankment of rivers in areas subject to tidal influence.

24. Dr. D N. Roy (Calcutta) read a paper on the possibility of certain salt water races of *A. subpictus* acting as carriers of malaria. He said that he had found some of the adults infected in nature

In connection with Dr. D N Roy's paper Dr P Sen said that although Dr. Roy's experiments were very interesting, one thing that struck him was that there was the possibility of his dealing with *A. sundaicus* instead of *A. subpictus*. In the larval stage it is so very difficult to distinguish between the two. As regards the natural infectivity of the species he was unable to confirm Dr. Roy's findings although he had dissected a large number of adult *A. subpictus* caught in the lake area

Mr M O T. Iyengar said that *Anopheles subpictus* was very extensively prevalent in the Salt Water lakes prior to the invasion of that area by *Anopheles ludlowi*—and yet no malaria was found anywhere in the area The spleen rates in 83 villages in that area were practically zero

Owing to the scarcity of cattle in the area, we ought to exclude the explanation that *A. subpictus* is zoophilic and that it is therefore not a transmitter in nature.

25. Mr M O T Iyengar said that the natural parasites of mosquitoes fell into the following groups (1) Bacteria, (2) Fungi, (3) Protozoa, (4) Nematodes, (5) Trematodes, (6) Insects, and (7) Acarines In this list, many of the parasites are of doubtful importance as agents checking the mosquito population. Judging from the morbidity caused in the insect-hosts and its pregnancy the following are of importance in India (1) Coelomomyces, (2) Microsporidia and (3) Mermithidæ

(1) *Coelomomyces.*

We have two species in India, *C indiana* and *C anophelesic*, both of which infest *Anopheles* larvæ and adults and cause considerable mortality Several species of *Anopheles* have been observed to be susceptible to this infection.

(2) *Microsporidia.*

Three genera of Microsporidia were recorded by him as infesting mosquito larvæ in India, namely, *Thelohania, Nosema* and *Plistophora*

(3) *Mermithidæ*

These worms live in the hæmocele of the host and cause considerable mortality. The parasitic stages are the larval phases, the adults being free-living and short-lived.

These three groups comprise the parasites that play a significant rôle in the natural control of mosquitoes in India. Our knowledge of these different

parasites is admittedly meagre; further studies are indicated in regard to their distribution, incidence, life-history and ecology Until further information on these points is available, it would be difficult to answer the question 'Can these parasites be utilized for a biological control of mosquitoes?'

VIII.

26. Dr. B M. Das Gupta stated that *P inui*, a quartan parasite occurring as a natural infection in *S irus*, had been successfully transmitted to a human volunteer in whose blood the parasites appeared 23 days after inoculation and in whom the infection persisted for one week The number of parasites observed in the blood of the volunteer was never high and recovery was spontaneous. Febrile symptoms were observed for three days only The stages of the parasite encountered were rings, trophozoites and schizonts. Gamotocytes were not found

Dr Krishnan said that Dr Das Gupta's finding was very interesting. The host parasite specificity is usually very rigid in plasmodial infections, but a few examples of successful cross-infection experiments are on record. This would be an additional example.

IX

27 Dr S L Hora said that he had studied the contents of the alimentary canal of a large number of specimens of *P panchax* collected from several localities in the Ballygunge, Tollygunge, Howrah and Pulta Waterworks areas His findings with regard to natural food of the fish confirmed those of Dr Sen, but he, at the same time, did not find many mosquito larvæ in the pieces of water inhabited by this fish. From experiments carried out in the field by introducing the fish in mosquito-breeding places, he concluded that *Panchax* preferred to feed on mosquito larvæ, and when their supply was almost exhausted they began to feed on other types of food, mostly insects and especially ants These results were confirmed by laboratory experiments, in which the fish were given a mixed diet of mosquito larvæ and other types of animals, such as Chironomid larvæ, Corixid bugs, may-fly nymphs, water mites, beetles, etc Under these circumstances the fish showed a definite preference for mosquito larvæ It was observed that, when kept with algæ, the fish preferred to starve rather than to feed on vegetable matter The voracity of feeding and the intensity of digestion of the fish were also studied

It was definitely found that *Panchax* was a very effective larvicidal fish and its use, under Indian conditions, was therefore strongly recommended.

In connection with Dr. Hora's paper Dr Sen said that he was grateful to Dr. Hora for the confirmation of his main findings on *Panchax panchax* within such a short time of publication of his paper. He had studied at least four kinds of so-called larvicidal fishes of Bengal, *Panchax panchax, Barbus*

stigma, *Esomus danricus* and *Trichogaster fasciata* and certain other species were under investigation He found that of all these fishes *Panchax* alone showed evidence of ingesting anopheline larvæ to the extent of 10 per cent as evinced by the analysis of stomach contents In his experience the *Panchax* did not exhibit any preferential activity towards Anopheles larvæ. It attacked all darting objects and that explained why in aquaria in the midst of other kinds of living organisms it attacked Anopheles larvæ so vigorously He reared the fish in the laboratory with both mosquito larvæ and ants. Not only adult ants but other strongly chitinized insects like beetles and chalcids were often found in the gut. This fish can also feed on algæ Dr Hora had cited Dr Fraser's observation and opinion that the shining structure (the third eye) on the head of the fish attracted adult mosquitoes, but so far as his observations go the adult mosquitoes were attacked by the fish at the time of their emergence from the pupæ when they were in a helpless condition because some time must elapse before they could use their wings There seemed to be some doubt about the usefulness in removing vegetation from water collections. In his experience clearance itself was a very good anti-larval measure. After the tank was cleared there was hardly any necessity of introducing fish *Trichogaster* was also carnivorous to a certain extent, but the other two fishes studied by him, that is *Esomus* and *Barbus*, were primarily herbivorous.

Several persons took part in the discussion and at the end Dr Hora briefly replied to the various points raised

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2	Dr K V Krishnan and N G Pai	Bio-chemical Changes in the Blood of Monkeys developing Malarial Hæmoglobinuria and their Significance in the Aetiology and Treatment of Blackwater Fever
3.	Dr D B. Dikshit	Pharmacology of Plasmoquine with special reference to its action in Pregnancy
4	Col R N Chopra, B M Das Gupta and B Sen	Experimental Studies on Ape Malaria with reference to its use in Malaria Therapy in nervous conditions.

II. Epidemiology

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6	Dr. A C Banerjea	Urban Malaria in the United Provinces
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9.	Dr. F de Mello	Malaria in Portuguese India *

* The papers marked with an asterisk will not be printed

III IRRIGATION AND MALARIA

10	Dr W C Sweet	Irrigation and Malaria
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27.	Dr S. L Hora and Mr K K Nair.	Observations on the Nutrition of *Panchax panchax*
28	Dr A G. Fraser (communicated by Dr Hora).	Observation on the Bionomics of *Panchax lineatus* †

* The papers marked with an asterisk will not be printed

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PRESENT POSITION OF ANTIMALARIAL DRUG THERAPY IN INDIA

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(Read at Symposium, August 27-28, 1937)

In this paper I propose to deal briefly with the present position with regard to drug therapy in malaria The antimalarial drugs may be divided into two main groups —

I The Cinchona derivatives

II Other antimalarial remedies This group includes most of the synthetic drugs

I CINCHONA DERIVATIVES

A *Cinchona alkaloids*

It is well known that as many as 20 alkaloids and probably more are present in the cinchona bark, all of which are chemically closely allied to each other These alkaloids have been divided into (i) crystallizable alkaloids, and (ii) amorphous alkaloids The former group only has antimalarial properties, the amorphous alkaloids have been shown to be inactive in this respect Of the crystallizable alkaloids present, four occur in large quantities, these are quinine, quinidine, cinchonine and cinchonidine Till recent years these alkaloids were the only drugs available which had specific action on the malarial parasites If given in suitable doses and under proper conditions their action in controlling malarial paroxysms is certain Of the four alkaloids quinine still holds the foremost position in the treatment of malaria though the antimalarial value of the other three alkaloids has been fully established From the data now available there is no room for doubt that quinidine, cinchonine and cinchonidine, in similar doses to quinine, are equally or very nearly as effective in the treatment of malaria In considering the relative therapeutic value of different alkaloids, it is of importance to take into account their effect in causing harm or inconvenience to the patient It may be said in favour of quinine, that it can as a rule be given in sufficient doses and for sufficiently long periods without danger to the patient Cinchonine is more nauseating than quinine and is liable to produce blurring of vision Quinidine is also more nauseating and has a powerful depressant action on the heart. Cinchonidine is neither toxic nor irritant but is distinctly the weakest of the four alkaloids

The importance of the fact that all alkaloids have marked antimalarial properties is very great to India where the economic condition of the people is low and purified quinine preparations, on account of their high price, are beyond the means of ordinary people. The reasons why quinine is more expensive than the total alkaloids of the bark are (i) That its proportion in the bark usually is a little more than half of the total alkaloids *Cinchona succirubra* and *Cinchona officinalis* barks, for example, contain about 5 to 6 per cent of the total alkaloids of which only 3 per cent is quinine *Cinchona ledgeriana* contains somewhat higher proportions. (ii) The cost of its separation from other alkaloids and purification further adds to its price. It would follow, therefore, that if the total alkaloids are used they will be cheaper than if only quinine by itself is used. It was for this reason that 'cinchona febrifuge' has been used in India and the League of Nations have introduced *totaquina* which contains 70 per cent of the total alkaloids of which 15 per cent must be quinine. By this means it is hoped that the treatment could be made less expensive and extended among the masses

Some of the other alkaloids of the cinchona bark which occur in smaller quantities than the four alkaloids stated above, for example cupreine and cupreidine compounds, have also antimalarial properties. Cupreine sulphate in doses of 1 gm. was found by Giemsa and Werner to be a good substitute for quinine in human malaria, but it is much more expensive and toxic Those observers also obtained good results with quin-ethyline and quin-propyline in doses of 0·3 to 0·4 gm in human malaria and with these compounds and quinamyline in bird malaria. Ethyl-hydrocupreine or optochin has been tried in malaria but it is a toxic compound.

The hydro-alkaloids are said by some to be more effective than ordinary salts. Giemsa and Werner, Baerman, MacGilchrist, Morgenroth, Goodson and many others have proved that hydroquinine as regards both its tolerability by the human subject and its parasiticidal action is superior to quinine Rabe and his co-workers have been successful in preparing hydroquinine synthetically, but the process is so costly that there is no likelihood of possible competition between the artificial and natural products

The disadvantages of the cinchona alkaloids are :—

(1) They have no action on the sporozoites injected by the mosquitoes and therefore they cannot have any really prophylactic action in this disease This was demonstrated by Yorke and Macfie (1924) who showed that 18 grains of quinine for 5 days before and 7 days after the mosquito bite failed to avert an attack of malaria, but if the drug was continued for 10 days, the disease did not develop. This shows that these alkaloids have little effect on the injected sporozoites but act on the asexual forms liberated from the infected red blood corpuscles.

(2) Cinchona alkaloids have little effect on the sexual forms of malignant tertian parasites. They, however, impede the formation of the pre-gametocytes

of *P falciparum* and may thus be regarded as directly schizonticidal and indirectly gametocidal

(3) They do not prevent relapses

(4) These alkaloids do not act uniformly on all strains of malaria

After the Great War there was a feeling against the use of cinchona alkaloids especially quinine and it was said that this drug was not effective against certain forms of malaria. Further investigation, however, showed that this was not due to any fault of the drug but due to their improper use

It has been proved by hæmatological and other evidence that the best method of administration of these alkaloids is by the mouth It is advisable to give them in the form of solution but owing to their bitter taste they may produce vomiting They can be given in the form of tablets so long as these are easily disintegrable. Subcutaneous injection finds few advocates Intramuscular injection should only be tried in those cases where administration by the mouth is not desirable or possible as it is liable to produce serious mutilation of parts *Intravenous method should only be used for severe and urgent cases* Parenteral method should not be used for routine administration of these drugs Intravenous injections must only be employed where the patient is comatose, or very gravely ill when an immediate response is necessary Any evidence of impending cerebral malaria is an imperative indication for injection treatment

On the appearance of acute symptoms of primary infection, quinine has a definite action from the third day onwards (second paroxysm of fever) in benign tertian malaria Its action is less rapid according to the strains of malignant tertian concerned and symptoms may continue until the fifth dose (third or fourth paroxysm).

As regards the time of administration of these alkaloids by the oral route, it is advisable to give them 2½ to 3 hours after a meal when the *gastric contents* are acid, the digestion has been complete and the stomach is nearly empty If given at this time they rapidly mix with the contents of the stomach and pass into the small intestine from where they are quickly absorbed into the circulation. There is less liability of their irritating the stomach if administered in this way.

Dosage.—Experience shows that in the case of Indian strains of malaria, a 5 to 7 days' course of treatment with 20 to 25 grains of the alkaloids daily is effective. Larger doses are not only wasted, but may do harm According to the Fourth General Report of the League of Nations, 0 5 gm of quinine hydrochloride sometime causes a temporary disappearance of trophozoites of benign tertian and quartan infection but a mean daily dosage of 1 gm for 5 to 7 days is often necessary to cause the trophozoites to disappear and not to make their reappearance in the peripheral blood after a latent period of varying lengths, in the course of first relapse In malignant tertian malaria 1 3 gm. produces analogous results It is also agreed that definite advantage is obtained by combining them with alkalies.

B *Preparations containing Cinchona Derivatives*

During recent years a number of cinchona derivatives have been used in the form of proprietary remedies whose composition is secret. Various claims have been made for these, amongst others that they have destructive action on both the sexual and asexual forms of all forms of parasites, that they prevent relapses and that they have prophylactic value. A number of preparations are on the market and we have tested some of these. Our observations show that their action is practically the same as cinchona alkaloids, they have no action on the gametocytes of malignant tertian, they do not prevent relapses and have no effect on the trophozoites Being proprietary remedies they are very much more expensive The following are some of the preparations in use :—

Malarcan.—Malarcan is said to be a compound of a stereo-isomeric base of methyl-cupreine with methyl-acridinium chloride and hydrocholic acid It is thus probably a derivative of quinine or quinidine

Tebetren.—Tebetren is described as methyl hydro-cupreine-methyl-acridine-dihydrocholate, i.e a compound in which quinine is combined with acridine (from which atebrin is derived).

Paludex—Another synthetic drug which has been recently introduced is paludex. It is a complex organo-metallic preparation containing copper joined to an oxyquinoline group Chemically paludex is cupro-oxyquinolin sodium sulphonate, and contains 8 37 per cent of metallic copper It is a greenish amorphous powder, readily soluble in water, forming a solution which is neutral in reaction and stable under ordinary conditions

Plasmodex is a similar compound, containing copper in a larger proportion

Esanofeles.—This is a proprietary preparation containing 0 1 gm of quinine bisulphate, 0 001 gm. of arsenious acid, 0 3 gm of iron citrate and some bitter principles If given in the prescribed form, it contains too little of quinine to be of any therapeutic value, specially against malignant tertian infection.

II. OTHER ANTIMALARIAL REMEDIES WHICH INCLUDE SYNTHETIC ANTIMALARIAL DRUGS

These compounds can be divided into two groups (1) Those which have action like the cinchona alkaloids on the asexual cycle, e g. atebrin, and (2) those whose main action is on the sexual cycle particularly of the malignant tertian variety, e g. plasmochin.

Neither of these compounds act on the trophozoites injected by the mosquitoes and therefore have no true prophylactic value. They do not prevent relapses though their action in this respect is said to be more powerful than that of cinchona alkaloids

Their dosage as compared with the cinchona alkaloids is much smaller, but they are more toxic.

(1) *Plasmochin.*—The shortage of quinine supply during the war led to experiments at Bayer-Meister-Lucius Research Laboratory at Elberfeld with the object of finding a synthetic drug which could be used in its place Schulemann and his colleagues chose methylene blue for investigation, they prepared a large number of compounds which were tested on canaries infected with *Plasmodium relictum* Among these compounds they found one which was particularly effective and this was an amino-quinoline derivative in which a basic aliphatic radicle was united to a quinoline nucleus by a connecting link of nitrogen. This compound was modified in many ways, and eventually the compound, first known as 'beprochin' and afterwards as *plasmoquin* or *plasmochin* was produced It was at first thought to have a definite curative effect in the treatment of all forms of malaria, but later experience showed that, while it was effective in adequate doses (which often produce toxic effects) in curing the benign tertian and quartan malaria by itself, in sub-tertian malaria it was of no therapeutic value because it had no action on the schizonts and some observers went so far as to say it had a provocative action It, however, possesses the remarkable and unique property of destroying the crescents in the peripheral blood

On account of this peculiar property of damaging the gametocytes it renders them non-infectious to mosquitoes Even such doses as 0 01 or 0 02 gm of plasmoquin daily are effective in this respect This remarkable effect against the more resistant form of the parasites is the greatest virtue of the drug but unfortunately it has little or no effect on the asexual form of malignant tertian parasites

It should be fully appreciated that plasmoquin is a drug which is likely to give rise to toxic effects and it should not be used for routine treatment of malaria It is combined with quinine, and it is claimed that this combination when continued for 2 to 3 weeks is more effective than quinine and the number of relapses is decreased Prolonged administration of this combination in therapeutic doses is likely to produce toxic effects but these are not so marked as a combination of plasmochin with atebrin Plasmoquin by itself thus holds a minor place in the symptomatic treatment of malaria

Cilional—The toxic effects produced by plasmoquin have been fully appreciated by the workers of Bayer's Scientific Laboratories and they have been busy in producing less toxic compounds. Cilional is one of these compounds which has been recently introduced and which according to preliminary experiments was not only more effective than plasmoquin but was considerably less toxic Trials on human beings show that this compound is certainly less toxic than plasmoquin but it is not so effective unless larger doses are given. The work in the School of Tropical Medicine has shown that this certainly is the case with the gametocytes from Indian species of *P. falciparum*

Atebrin—The work of Schulemann and his colleagues at Elberfeld, which culminated in the synthesis of plasmoquin, was continued by Mietzsch and

Maus. More than 1,200 compounds were prepared and eventually the drug originally called 'erion' and now known as atebrin was produced. Chemically it is the dihydrochloride of an alkylamino-acridine derivative and is a yellow powder with a bitter taste. Its solubility in water is 1 in 14 and it forms a neutral fluorescent solution. The action of atebrin is very similar to quinine, but according to some workers it is more effective than quinine in reducing the number of relapses. None of these drugs by itself nor any combination thereof, such as atebrin and plasmoquin or quino-plasmochin, represents a *therapia magna-sterilisan*.

Chopra and his co-workers (1933) carefully tested this drug on the Indian strains of malaria and have come to the following conclusions :—

(1) Atebrin is an effective drug in the treatment of Indian strains of malaria Its destructive action on the asexual forms of benign tertian, malignant tertian and quartan types of malaria is about equal, the schizonts disappearing from the peripheral circulation after 0 6 to 0·9 gm of the drug

(2) The sexual forms or gametocytes are more slowly acted upon than the asexual forms. The gametocytes of the benign tertian and quartan types are readily destroyed The gametocytes of the malignant tertian type are not affected at all.

(3) The drug is effective in doses of 0·1 gm. three times a day, the course lasting for five days, making a total of 1·5 gm of the drug for the cure The drug can be given intravenously in doses of 0·1 gm to 0 3 gm. dissolved in 1 to 2 c.c. of distilled water when the number of parasites in the peripheral blood is large.

(4) In chronic types of malaria the drug is effective and produces a rapid reduction in the size of the spleen.

(5) Atebrin has earned a great reputation as a powerful remedy in preventing relapses in all species of human malaria In view of clinical evidence, the drug would appear to be more powerful than quinine in curing malaria but so far as prevention of relapses is concerned this is not the experience with Indian strains of malaria.

Atebrin musonat —This form of atebrin has come into prominence through trials made during the recent epidemic in Ceylon It is simply an improved form of a soluble atebrin salt suitable for injection, 0·3 gm. of atebrin being contained in 0·375 of the salt. Hecht has shown that when atebrin is administered by mouth much of it is retained in the upper intestine, liver and bile, and only overflow goes to the peripheral circulation after these organs are saturated. This exceptionally high concentration of atebrin is responsible for the manifestation of toxic symptoms By injections the drug gets into the circulation quicker and gives response earlier Doses from 0·1 to 0·37 gm. are given and a single injection often produces remarkable effects on the clinical symptoms, but recrudescence usually occurs in a few days. Two similar injections on successive days, however, proved sufficient to control the temperature within 48 hours and in four days all forms of benign tertian

parasites and the ring forms of malignant tertian are destroyed. Crescents are not affected and must be destroyed by plasmoquin. The intravenous route can be used, but this method apparently produces no quicker response than does the intramuscular and by some is not considered free from risk The drug though quickly absorbed is quickly excreted and relapses are said to be more frequent with intravenous injections

It has been reported that some cases of malaria fail to respond to quinine and are controlled by atebrin and *vice versa* This may be due to a number of factors which interfere with the proper absorption of these drugs The parasiticidal effect of neither of these drugs is immediate and takes a certain time to manifest itself

Toxic effects of atebrin —Atebrin even in therapeutic doses produces yellow staining of the skin which may take weeks to disappear It may also occasionally produce headache, abdominal discomfort or colic, but cyanosis frequently met with plasmoquin is not seen There appears to be no doubt that cases of psychoses of various forms and other cerebral complications have been associated with its use.

Relapses and Prophylaxis —Quite a large number of malarial patients get relapses occurring within a few weeks to a few months after treatment, whether quinine or atebrin is used. Relapses are said to be less common with synthetic drugs than with cinchona alkaloids but neither of these drugs completely eradicates the infection Although they have remarkable parasiticidal power over the asexual forms which produce clinical manifestations of the disease, their action on the gametocytes is much feebler and on the sporozoites negligible As regards sporozoites there is evidence to suggest in bird malaria that there may even be a further cycle in the vertebrate host, and that sporozoites may not all directly give rise to asexual forms in the blood but may undergo schizogonic cycle of their own in the cells of the reticulo-endothelial system. In this form unharmed by drugs they may exist as a reservoir from which the blood may get subsequently re-infected and produce clinical relapse This has not yet been demonstrated in the case of human malaria

A number of anti-relapse treatments are suggested, the best for this country is 7½ to 10 grains of quinine twice daily for two consecutive days in the week for two months following the original course, or 5 to 7½ grains may be taken daily for a like period. In the case of atebrin a 5 days' course of 0 1 gm thrice daily repeated at intervals of a week or 10 days is suggested

The reason why daily doses of quinine is often suggested as a prophylactic when its action on the sporozoites is negligible is that, although quinine and atebrin may not be lethal to sporozoites, their presence in the blood tends to suppress the multiplication of asexual forms and so inhibits clinical manifestations For prophylaxis, 5 grain doses of quinine daily or larger doses at correspondingly longer intervals have been used Some use 0 3 gm of atebrin weekly, but with this drug it is difficult to strike a balance with a dose which is effective and which is free from undesirable effects.

Both quinine and atebrin have been combined with plasmoquin in preventing relapses and as prophylaxis, but this is not considered desirable

Atebrin and Plasmochin combination —As atebrin only acts on the asexual forms of malignant tertian parasites it has been combined with plasmoquin. A comparative study of the action of atebrin and atebrin-plasmochin combination on Indian strains of malaria by Chopra and co-workers (1936) showed that, (1) in cases of benign tertian and quartan malaria the combination of the two drugs is not more effective than atebrin alone in so far as the time of disappearance of the parasites from the blood is concerned; (2) in the case of malignant tertian infection, however, the combination appears to be more effective and the parasites disappear more rapidly from the peripheral circulation. (3) with regard to the relationship between the number of parasites and their disappearance from the peripheral circulation, atebrin alone and atebrin-plasmochin combination behave in the same way. (4) the relapse rate is definitely lower in cases when the combination of the two drugs is used. (5) the combination of the two drugs is more toxic.

It is therefore recommended that in those cases where crescents are present, a 3 days' course of plasmoquin 0 01 gm twice daily be given after the course of atebrin is completed The toxic effects are thus eliminated.

ANTIMALARIAL DRUGS IN APE-MALARIA

A few words may be said about the action of these drugs on ape-malaria It has been shown that *P knowlesi* produces a very intense and virulent infection in *Silenus rhesus*, causing death of the animal if untreated This plasmodium appears to be more closely related to that occurring in man than plasmodia occurring in birds which are usually used for testing antimalarial drugs The results obtained should therefore be more readily applicable to man Chopra and Das Gupta (1933) showed that the destructive action of atebrin on *P knowlesi* was exceptionally powerful Usually two doses of 0·025 gm. of the drug given intramuscularly or intravenously are sufficient to control a very heavy infection which may amount to a million parasites per c.mm of blood. The drug affected equally the schizogony and the gametogony. Owing to its slow excretion, atebrin appears to exert a more prolonged action than quinine and atebrin is successful in checking a heavy infection whereas quinine may not. It was, however, shown that even after five days' intensive treatment with atebrin, the parasites invariably reappeared in the monkeys in 10 to 15 days and multiplied with the same rapidity as in the previous attack, causing death of the animal if prompt treatment was not given. The recrudescence can, however, be checked more easily, one dose sufficing to control the multiplication of the parasites. After this a low grade of infection persists for long periods, the parasites losing their virulence. In contra-distinction to the action of atebrin, quinine according to Chopra and Das Gupta (1934) has a much less powerful immediate effect on these parasites. When the parasite count is low, i.e. below

100,000 per c mm., one dose (intramuscular or intravenous) may be effective in controlling the infection, but when the parasite count is higher, 2 or 3 injections are necessary to control the infection. Further, the first effect of injection may be an actual increase in the number of parasites The advantage of quinine is that relapses rarely occur after the treatment of the primary infection, and even when they do occur, they are not often fatal The action of quinine thus appears to be slower and if the treatment is started at a time when the infection is moderately heavy, the infection does not seem to be effected, in most cases, in 24 hours or even longer with quinine, whereas with atebrin even if treatment is started late, i e when the count exceeds half a million parasites per c mm , this invariably falls to a negligible number

Stimulated by the results of these experiments, further work has been carried out on the concentration attained by these drugs in the circulating blood at different intervals of time in relation to parasite count With regard to quinine, Chopra, Ganguli and Roy (1935) have shown that there is no direct relationship between the concentration of quinine in the blood and the parasite count at any particular time The highest concentration of the alkaloid attainable without producing toxic effects produced no apparent reduction in the number of parasites nor degenerative changes in them The action of *quinine thus appears to be synergistic to other defensive mechanisms set up* in the body In therapeutic doses quinine augments these processes or possibly it acts on the parasites in such a way as to render them more vulnerable or unable to propagate Studies on the concentration of atebrin in the blood by Chopra, Ganguli and Roy (1936) show that the highest concentration of atebrin occurs between half an hour and six hours after the injection of atebrin The number of parasites per c mm of blood distinctly diminishes in the majority of cases in the first 6 hours when the concentration of atebrin in the blood is highest Within 24 hours the parasites are reduced to a negligible number even in spite of the concentration of atebrin rapidly falling off. It is, therefore, reasonable to state that atebrin, unlike quinine, has probably some direct lethal action on *Plasmodium knowlesi* in vivo. This has been further confirmed by Chopra, Das Gupta and Roy (1936) who showed that atebrin solution in a dilution of 1 in 50,000 *in vitro* is capable of destroying the parasites even when the infection is heavy. The smears of blood which were kept in contact with atebrin showed degenerative changes in the parasites. This work is being further elaborated

Three important points which have come out of this work are

(1) Atebrin has a more powerful and more rapid effect on *P knowlesi.* Whereas quinine takes 24 hours to produce its effect, atebrin is effective in 6 hours and concentration of this drug runs parallel with the decrease in the number of parasites

(2) Atebrin has some direct action on *P knowlesi* (1 in 50,000 concentration), quinine has not In fact the first effect of quinine administration may be an actual stimulation of growth of parasites.

(3) A fatal relapse is more common after atebrin than after quinine. The action of quinine, though less powerful and less rapid, appears to be more prolonged and lasting

Whether all these are applicable to human malaria remains to be seen.

CINCHONA ALKALOIDS *versus* SYNTHETIC ANTIMALARIAL DRUGS.

What is going to be the effect of the introduction of these powerful synthetic antimalarial drugs on the cinchona alkaloids? Are these old veterans going to be entirely replaced by the new-comers? The Malaria Commission of the League of Nations has rightly pointed out that neither of the two groups, however intensive the treatment may be, is *therapia magna sterilisans* and their effect in preventing relapses is not marked They also have no true prophylactic action The synthetic drugs, according to the Commission, are not to be regarded as 'substitutes for quinine but as additional weapons for use in particular circumstances and for special purposes'.

This, I have no doubt, is the correct point of view. The cinchona alkaloids have a very low degree of toxicity and can be used with impunity in the mass treatment of malaria and even self-medication by the patient without any danger of serious harm. The same cannot be said about the synthetic antimalarial drugs They have a high degree of efficiency combined with toxicity and should always be used under proper medical supervision Even under such conditions, toxic effects are frequently met with. Unless further researches produce less toxic drugs, and I may say that efforts are being made in this direction—cinchona alkaloid will hold the field for treatment of malaria generally.

During the last few years, it has been debated whether the cinchona plantations in this country should be extended. One of the arguments brought forward against their extension is that in view of the rapid development of synthetic antimalarial drugs there will be no further necessity for cinchona alkaloids. I personally feel no hesitation in saying that unless something extraordinary happens, for the next 15 to 20 years, we shall have to use the cinchona alkaloids in our struggle against malaria in India The cinchona plantations take 7 to 8 years to mature and if we wish to extend the treatment of malaria among the masses, which is one of the chief methods of eliminating this disease, it is very desirable that cinchona plantations should be extended till such time as an effective and harmless synthetic drug is available which can be used for mass treatment of malaria without any special supervision.

In Formosa large areas have been put under cinchona plantations and in a few years' time Japan will be able to meet all her own requirements. In India large scale and economic production should be taken in hand now that information is available regarding the species of cinchona which yield the highest percentage of the alkaloids and the best soil for cultivation. It may be ten years before India, even if she starts work at once, can hope to produce all

the cinchona alkaloids her population needs, but in the meantime it should be possible to overhaul the existing resources It is a health rather than a fiscal problem.

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BIOCHEMICAL CHANGES IN THE BLOOD OF MONKEYS DEVELOPING MALARIAL HÆMOGLOBINURIA AND THEIR SIGNIFICANCE IN THE ÆTIOLOGY AND TREATMENT OF HUMAN BLACKWATER FEVER.

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In a large number of diseased states important biochemical changes are induced in the animal body and a careful study of these changes furnishes data of value in diagnosis and prognosis of the disease. Even when one is dealing with a disease of unknown ætiology, a study of the blood chemistry sometimes affords suggestive information on the probable nature of the causative agent and indicates the lines of treatment that might be profitably employed. The study of the biochemical changes taking place in the blood of hæmoglobinuric monkeys suggested that the sudden severe hæmolysis leading to hæmoglobinuria in human blackwater fever may be the direct outcome of the biochemical alterations induced in man as a result of chronic malarial infection. Our detailed investigations on the biochemical changes taking place in the blood of hæmoglobinuric and non-hæmoglobinuric monkeys during the different stages of the disease, with special reference to those chemical constituents that are known to be associated with the phenomenon of hæmolysis, such as cholesterol, inorganic and organic phosphorus and glucose, brought out the fact that in the pre-hæmoglobinuric stage the following changes are conspicuous: (*a*) a fall in glucose and a rise in inorganic phosphorus, (*b*) a rise in cholesterol esters, and a fall in total cholesterol in a fair number of cases and a marked fall in free cholesterol in all cases, and (*c*) a rise in organic phosphorus. The interpretation and significance of these variations are discussed below.

FALL IN GLUCOSE AND RISE IN INORGANIC PHOSPHORUS.

This was a constant feature in all the hæmoglobinuric monkeys studied. The fall in blood sugar got more pronounced as the infection in the animal got more intense. There are three possible ways of explaining this depletion of glucose: (*a*) that it is due to the utilization of the sugar by the parasite; (*b*) that it is due to the burning up of the sugar by the body to a greater extent; and (*c*) that it is due to an upset in the glycogenolysis and also in the mobilization of sugar. The fact that a rise in inorganic phosphorus is associated with this fall in glucose in monkeys shows that the animal is not

utilizing the sugar in the normal way The parasites need sugar for their multiplication and growth and they probably obtain this from the hexose-phosphates of the red cells. The inorganic phosphorus arising out of this hydrolysis of the hexose-phosphate probably accounts for the increase in this substance. When insulin and sugar are administered to these monkeys it is found that this rise in the inorganic phosphorus does not take place. This shows that the accumulation of the inorganic phosphorus is essentially due to the upset in carbohydrate metabolism. The bearing of this upset on the hæmolytic process is not clear. In hæmoglobinuric monkeys it is possible to maintain normal levels for glucose and inorganic phosphorus through injection of glucose and insulin but by doing this the hæmolytic process is not inhibited, showing that the observed changes in these constituents, whatever be their underlying causes, have no direct bearing on the hæmolytic process.

In human blackwater fever, although a similar depletion of glucose has not been observed, all studies indicate that a rise in inorganic phosphorus does occur in a certain percentage of cases. This rise has however been explained as being due to renal dysfunction. Even if the change was due to an upset in carbohydrate metabolism there is no evidence to show that it plays a direct part in the hæmolytic process.

Fall in Free Cholesterol, Rise in Ester Cholesterol and Fall in Total Cholesterol in a certain percentage of cases

Fall in free cholesterol was a constant feature in all monkeys developing hæmoglobinuria. In view of the property of free cholesterol to inhibit hæmolysis caused by saponin, etc., this observation is of particular importance. The constancy with which the hæmoglobinuria is associated with a marked fall in free cholesterol suggests that the hæmolysin is probably one whose activity can be inhibited by cholesterol This is supported by the observations that in non-hæmoglobinuric monkeys free cholesterol was invariably high or normal. This shows that if mobilization and synthesis of free cholesterol kept pace with the increased production of fatty acids no hæmolysis or hæmoglobinuria would result

The marked rise in ester cholesterol suggests that prior to the onset of hæmoglobinuria there is an increased production of fatty acids and that these acids are being transported in the form of esters to the tissues. If this is correct then the fatty acids may be considered to be the hæmolytic agents that act when free cholesterol is not present in sufficient amount. Thus the synthesis and mobilization of free cholesterol appear to be of greatest importance in the prevention of hæmolysis and hæmoglobinuria.

In human blackwater fever all previous workers have estimated only total cholesterol and that too after the onset of hæmoglobinuria. The results have therefore not only been variable but also inconclusive. We have in 8 cases of human blackwater fever estimated the blood cholesterol as free

and ester cholesterol separately and the results obtained are in conformity with the findings in monkeys. The results suggest that in human blackwater fever the hæmolytic agent is a fatty acid that acts when free cholesterol is not present in sufficient amount.

Now the question arises as to why there should be an increased production of fatty acids in malaria and in hæmoglobinuria, several explanations are possible. (1) Increase in fatty acids may be due to the growth and multiplication of the parasite (2) Increase in fatty acids may be due to an increased demand for purposes of repair and regeneration of damaged tissues (3) Increase in fatty acids is the result of an upset in carbohydrate metabolism and fat metabolism. (4) Increase in fatty acids is due to an increased demand of the substance for the purpose of disposal of the inorganic phosphorus that is accumulating and for converting this into the organic form (5) Increase in fatty acids may be the result of damage to the liver There is some evidence to substantiate a few of these possibilities in monkeys but the evidence in favour of liver damage being the cause of fatty acid production is overwhelming In the case of man, where blackwater fever is not associated with an intense parasitization as in the monkey and, where there is no evidence of a deranged carbohydrate metabolism, the only possible explanation is a damaged liver Pathologically also there is evidence to show that there is such a damage This damaged state of the liver can very well account for an abnormal fatty acid production in human blackwater fever as well

The next question is as to why the synthesis and mobilization of free cholesterol should fail. Here again a study of the pathology of the liver and adrenals in man and monkeys has shown that the most striking change is a fatty degeneration and focal necrosis of the liver and degeneration of the adrenal cortex As these two organs are recognized to be closely associated with cholesterol metabolism it can readily be understood why cholesterologenesis and mobilization should fail. Another possible explanation for the depletion of cholesterol is the associated damage to the reticulo-endothelial system which is an important storehouse for cholesterol in the body

RISE IN ORGANIC PHOSPHORUS.

The rise in organic phosphorus as lecithin, namely the alcohol ether soluble fraction, was noted in both hæmoglobinuric and non-hæmoglobinuric monkeys towards the later stages of the infection. Such rise in organic phosphorus may be explained in any of the following three ways. (1) that it is derived from the destroyed R.B.C, (2) that it indicates a method of disposal of the excess of fatty acids and inorganic phosphorus that is being produced; and (3) that it indicates an upset in fat metabolism due to liver injury Of these, there is ample confirmation of the last explanation. As regards human blackwater fever, the alcohol ether soluble phosphorus compounds, namely lecithin and

other allied derivatives, have not been previously estimated. In the 8 cases studied by us we noted a rise in this constituent as in monkeys.

The increase in organic phosphorus raises a very important question regarding the nature of the hæmolysin involved and the rôle of lecithin in the hæmolysis of blackwater fever. As this increase of organic phosphorus in monkeys was noted in both the hæmoglobinuric and non-hæmoglobinuric groups it looks at first sight that the increase in this constituent may have nothing to do with the hæmolysis. But the fact that in the former the rise in lecithin is associated with a marked fall in free cholesterol suggests that the hæmolysin is one that is not only inhibited by excess of free cholesterol but also activated by the presence of excess of lecithin.

From the above discussion it will be seen that the phenomenon of hæmoglobinuria both in man and in monkeys is determined by the manner in which the host reacts to the stimulus of malarial infection. The production of the hæmolytic agent, as well as the conditions that favour its action, seem to be the result of altered metabolism due principally to liver injury. Whatever the true nature of the hæmolysin may be it is clear that its action is definitely inhibited by excess of *free cholesterol*. So in the treatment and prevention of blackwater fever we should aim at the following: (1) preventing liver injury or correcting the consequent alterations in fat metabolism; (2) stimulating the cholesterologenetic centres in a manner such that the synthesis and mobilization of free cholesterol will keep pace with the increased demand; and (3) stimulating the reticulo-endothelial system so that phagocytosis and the cholesterol stores of the body may be maintained. Our preliminary studies show that all these can be accomplished to a certain extent by injections of glucose, ascorbic acid and cortin.

PHARMACOLOGY OF PLASMOQUINE WITH SPECIAL REFERENCE TO ITS ACTION IN PREGNANCY

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(*Read at Symposium, August 27-28, 1937*)

Plasmoquine was prepared by Schulemann and his colleagues in 1924 and became available for general clinical use in 1926 Soon after its introduction into therapeutics it attracted considerable attention and a very large number of papers were published in succeeding years describing the clinical use of plasmoquine. Experimental studies on this new antimalarial drug were, however, remarkably few and a complete account of its pharmacological action was lacking. The author (1936) has already reported the principal pharmacological actions of this important drug. The toxicity tests on dogs, cats and rabbits agreed with those reported by Le Heux and Wijngaarden (1929) In guinea-pigs the dose which killed 50 per cent of the population after oral administration was found to be in the neighbourhood of 20 mg per kg The action of the drug on protozoa and bacteria was, however, not marked, e g. a concentration as high as 1-1000 was required to inhibit the growth of *B. coli* or *B pestis*.

The antipyretic action of plasmoquine was studied in rabbits with *B coli* fever. It was found that smaller doses of plasmoquine (3 mg per kg) did not lower the temperature Toxic doses of the order of 10 mg per kg , however, reduced the normal as well as the fever temperature Although smaller doses of plasmoquine did not by themselves reduce the fever temperature, it was found that in combination with quinine such doses reduced the temperature quicker than did quinine alone.

The R.B.C. count or the hæmoglobin percentage was not affected by administration of therapeutic doses (1 mg. per kg) of plasmoquine in guinea-pigs. The fragility of the animal as well as human R.B.Cs. was unaffected by comparatively larger doses of the drug. The important action on the blood was that of methæmoglobin formation and the lowest concentration of plasmoquine that led to a definite formation of methæmoglobin detected spectroscopically was about 1 in 10,000.

The cardiovascular system was markedly affected by this drug. Intravenous injections of therapeutic doses (1 mg. per kg.) of plasmoquine produced a transient fall in blood pressure with rapid recovery in cats and dogs. Larger doses (2 mg. per kg) produced a considerable fall in blood pressure accompanied by an irregularity of the heart. This irregularity was studied electrocardiographically and it was found that the normal action of the pace-marker was completely upset and most of the ventricular contractions were abnormal.

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The digestive system was also found to be considerably affected by the drug. Movements of the gastro-intestinal tract were studied in animals with a gastric fistula and were found to be inhibited by larger doses of plasmoquine. Similarly acute experiments in intact animals and also experiments with isolated gut showed that plasmoquine inhibited gastro-intestinal motility. The important action, however, appeared to be on the liver and in a large number of experiments toxic doses (15 to 20 mg. per kg.) of plasmoquine administered orally or hypodermically were found to produce a fatty degeneration of the liver in guinea-pigs.

The action of plasmoquine on the central nervous system was studied by introducing the drug into the cerebro-spinal fluid of the Cisterna magna of dogs and cats. Such administration produced a marked depression of the vasomotor and respiratory centres

The action of plasmoquine on the female reproductive organs was studied in detail so as to see how it would influence the course of a normal pregnancy The effects on the animal uteri *in vivo* and *in vitro* were therefore studied. Cats, dogs, rabbits and guinea-pigs were used for the purpose and both the pregnant as well as the non-pregnant uteri were experimented upon On the isolated uterus, plasmoquine was found to produce a slight contraction of the uterus in low concentration such as 1 in 300,000 Higher concentrations of the order of 1 in 100,000 or more, however, produced the opposite effect, viz a relaxation and this was true for the pregnant as well as the non-pregnant uteri.

In intact animals, the uteri of cats and rabbits were found to be more susceptible to the action of plasmoquine than those of dogs In cats a dose of 1 mg. per kg. usually produced a slight contraction of the uterus, while in dogs a dose of about 1·5 to 2 mg per kg. was required to produce the same effect. Pregnant uteri of these animals responded to plasmoquine in the same way as did the non-pregnant ones. Although plasmoquine contracts the isolated and the intact uterus in low concentrations, it has the remarkable property of counteracting the effects of other uterine stimulants such as quinine or pituitrine. Thus, on the isolated rabbit's uterus a 1 in 500,000 dilution of plasmoquine produced a stimulant effect as did a 1 in 100,000 of quinine A combination of the two, however, failed to produce any demonstrable effect on the tone or movements of an isolated rabbit's uterus Similar but less marked inhibitory action was also seen in the intact uterus of experimental animals.

In order to get an idea of the response of the human uterus to plasmoquine, experiments were made on fresh strips of human uterus, in the same way as on the animal uteri. For this purpose strips from both pregnant and non-pregnant human uteri were obtained and suspended in warm oxygenated Locke's solution. The response, both in the gravid and the non-gravid uteri, was similar, although the gravid uterus was more sensitive to the drug. The nature of response of the human uterus was similar to that of animal uteri, low concentrations causing a contraction and higher ones a relaxation of the

uterine muscle These observations were reported by the author in 1937. As the isolated human uterus responded to plasmoquine in the same way as did the isolated animal uteri, the response of the intact human uterus should also be similar to that of the intact animal uteri The action of plasmoquine on the intact animal uteri is referred to above In those experiments, however, the animal was under the influence of a general anæsthetic Experiments were therefore made to see the effect of plasmoquine on the uterine movements of animals without administering any anæsthetic Reynold's (1930) technique was followed for the purpose With aseptic precautions a vaginal fistula was made in rabbits in such a way that the two uterine openings were pointing outside through the vaginal cuff, which was sutured to the anterior abdominal wall The animal was allowed to completely recover from the operation and after complete recovery a small balloon was inserted into one of the horns, filled with water and connected to a Marey's tambour Continuous tracings could thus be obtained and the effects of a therapeutic course of plasmoquine, given over a period of five days or more, could be recorded graphically Such experiments showed that a single intravenous injection of a small dose (1 mg per kg) of plasmoquine produced only a slight transitory contraction of the uterus, while a therapeutic course of plasmoquine (0 5 mg per kg) given orally over a period of five days did not in any way affect the normal contractions of the uterine muscle during the course of treatment or some days after cessation of administration of the drug The drug given in therapeutic doses orally, therefore, did not seem to modify the normal contractions of the uterine muscle.

Finally, to see if plasmoquine affected the normal course of pregnancy toxic as well as therapeutic doses of the drug were given to pregnant guinea-pigs which were in various stages of pregnancy Toxic doses of the order of 15 to 20 mg. per kg. produced death of the fœtus along with the death of the mother The death occurred from 2 to 7 days after administration of the drug and showed that even high concentrations of plasmoquine circulating into the blood did not produce sufficient action on the uterine muscle so as to induce an abortion

The effect of therapeutic doses of plasmoquine was similarly studied in guinea-pigs. A dose of 0 5 mg per kg was administered orally to 12 guinea-pigs in various stages of pregnancy None of these showed any signs of premature delivery and all delivered a normal litter in due course

Discussion.

The experimental data given above shows that plasmoquine is liable to affect most of the systems of the body especially the cardio-vascular and the digestive systems. The cardiac irregularities are produced by intravenous injection of the drug and therefore this method of administration should be avoided. The liver seems to be the organ which is very often affected by toxic doses of the drug and it is likely that some of the toxic symptoms seen

after clinical use of the drug may originate in that organ. The action on the reproductive system, however, appears not to be harmful and there is some evidence to believe that even large doses fail to interrupt the course of a normal pregnancy. The fact that a combination of quinine and plasmoquine antagonizes the stimulant effect of each on the isolated uterus is interesting from a clinical point of view for such a combination has proved useful in the treatment of malaria.

Summary and Conclusions.

(1) Toxicity tests on protozoa and bacteria show that plasmoquine is not toxic to these.

(2) Plasmoquine has no antipyretic action of its own, but in combination with quinine it lowers temperature quicker than quinine alone.

(3) The cardio-vascular system is depressed by small doses of plasmoquine. Large doses produce a cardiac irregularity.

(4) The gastro-intestinal motility is depressed and toxic doses produce a fatty degeneration of the liver.

(5) The contractions of the isolated human or animal uterus are increased by low concentrations of plasmoquine and decreased by high ones.

(6) Contractions of the intact animal uterus are not affected by administration of therapeutic doses of plasmoquine given over a period of five days.

(7) Therapeutic or even toxic doses of plasmoquine given to pregnant guinea-pigs do not produce an abortion.

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EXPERIMENTAL STUDIES ON APE MALARIA WITH REFERENCE TO ITS USE IN MALARIA THERAPY FOR NERVOUS CONDITIONS.

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(*Read at Symposium, August 27-28, 1937.*)

Since the successful transmission of monkey malaria to human beings by Knowles and Das Gupta (1932) it has been tried by some workers in the treatment of nerve syphilis.

Van Rooyen and Pile (1935) treated 12 cases of general paralysis of the insane. These observers noted that there existed a marked variability with regard to the degree of susceptibility to infection with this parasite. Although the majority of the individuals inoculated with the blood of infected monkeys were readily infected, a few showed marked refractoriness in that the infection failed to establish itself in these individuals. This resistance was particularly noticeable in the case of patients who had previously received a course of benign tertian malaria therapy. These workers were unable to assess the value of this mode of therapy, for their observations on these cases were very short. But they hoped that monkey malaria might ultimately prove to be an effective substitute for *P. vivax* in the treatment of G. P. I. According to these observers atebrin has little or no effect on the reduction of temperature or destruction of the parasites (*P. knowlesi*).

To determine whether monkey malaria could be employed for malaria therapy in nervous cases we have made the following inoculation experiments.

Case I.—This is a case of optic atrophy with a history of syphilis and moderately positive Wassermann reaction.

***History of inoculations*:** On 3-1-36 he was inoculated with 0.5 c.c. of blood showing a massive infection with *P. knowlesi* (8,240 parasites per 100 leucocytes). Temperature began to rise on the 15th day of inoculation and persisted for a week. Fever was of the quotidian type and varied from 102–104°F. Infection died out spontaneously. He was now examined by the ophthalmologist who reported that the condition of the eye was the same as before, but the patient felt that his eye-sight had appreciably improved. About 9 months later he came under our observation again. It was now decided to give him another course of fever. Accordingly he was re-inoculated with *P. knowlesi*. A much bigger dose than in the previous inoculation was used. As the patient showed absolute resistance to *P. knowlesi*, he was injected with *P. vivax*. Infection was readily established. After he had 9

rigors the patient was given a course of quinine treatment. His eyes were examined again, but no improvement was observed. About 6 weeks after the experimental infection with *P vivax,* he came back with fever showing typical benign tertian periodicity and scanty parasites (*P. vivax*) in the blood. It is not possible to say whether this was a relapse or whether he contracted a fresh infection during his stay at Jessore, a place which is reputed to be a hot-bed of malaria in Bengal

Case II —The patient was suffering from advanced optic atrophy with derangement of mental condition—restlessness alternating with depression and disorder of speech. Wassermann reaction was strongly positive.

History of inoculations: On 30-1-36 he was inoculated with 0 8 c.c of blood from a *S rhesus* heavily infected with *P knowlesi* (4,200 parasites per 100 leucocytes). On the 14th day of inoculation temperature started rising and blood showed scanty parasites in the thick films Three days later temperature rose to 104 6°F., although the parasite count was low (529 growing trophozoites and schizonts per 1,000 leucocytes). At this stage the patient became semi-conscious with marked rigidity of the neck. So it was decided to terminate the fever. A dose of atebrin (0 1 gram) was given by the mouth. As the patient showed sensitiveness to atebrin as evidenced by nausea and yellow colouration of the skin 0 5 gramme of quinine was given by intramuscular injection. Within 24 hours temperature came down to normal and all the symptoms passed off. On 4-4-36 he was re-inoculated with a large dose of *P. knowlesi* without infection resulting. On 24-9-36 he was inoculated with *P vivax* and was readily infected There was irregular pyrexia for 11 days, which subsided spontaneously Again on 11-2-37 he was inoculated with the blood containing a mixed infection with *P. vivax* and *P falciparum*. After a short incubation period of 8 days he developed high temperature (105·2°F.), showing only the rings of *P. falciparum.* Fever was controlled with 0·2 grammes of atebrin daily for 3 days On 12-3-37 fever recurred, associated with only *P. vivax* (almost all phases) in the blood. After 6 rigors with high temperature (rising up to 104°F or even more) further progress of the infection was checked by a full course of atebrin. There was no noticeable improvement in the patient's condition.

Case III.—The case is one of primary optic atrophy with negative Wassermann reaction

History of inoculations: On 6-4-36 he was inoculated with 2 c.c. of blood from a *S. rhesus* heavily parasitized with *P. knowlesi.* He started getting fever on 12-4-36. Parasites first appeared on 18-4-36. Temperature never rose above 102°F. and came down to normal on 26-4-36. No antimalarial treatment was given. On 1-6-36 he was inoculated with 4 c.c. of blood (1,280 parasites per 1,000 leucocytes) from a case of benign tertian malaria. On 18-6-36 scanty parasites were found in the thick smears. There was a slight rise of temperature on 10-6-36. Since this date he became completely afebrile. In March 1937, he was inoculated for the second time with 5 c.c. of blood from

a very heavily infected *S rhesus* (80 per cent of the animal's red cells infected with one or more parasites). Even such a massive dose failed to produce an infection.

Case IV.—The patient was suffering from mental deterioration—delusion of being constantly persecuted by his relatives. Wassermann reaction was strongly positive.

History of inoculations: On 1-5-36 he was inoculated with a massive dose of *P. knowlesi* from a heavily infected *rhesus* monkey. He started getting fever on 11-5-36 and the parasites were first detected in the blood two days later. After the fever had continued for 10 days it was considered necessary to cut short the attack as the patient was much pulled down and complained of cardiac discomfort. Accordingly he was given a dose of 0·2 gramme of atebrin by the mouth and the temperature came down to normal within the next 12 hours. There was distinct amelioration of his mental condition, but it did not last long. Two months later, he was again brought to one of us (B.M.D.) who thought that another course of febrile attack might be tried with benefit. So he was inoculated with 5 c.c of blood from a case of benign tertian malaria showing moderate infection Fever started on the 13th day of inoculation. After the patient was allowed to have 8 well-marked rigors the infection was cut short by a single dose of 5 grains of quinine. Apparently not much benefit was derived by the patient from this course of fever. About 3 months later the patient came under our observation again and his relations insisted on giving him another course of malaria therapy. On 4-5-37 we injected him with the blood from a patient who was suffering from benign tertian malaria, blood smears showing chiefly growing trophozoites. On the 9th day of inoculation he had high temperature and curiously enough the blood films showed only rings of *P. falciparum*. (The specific identification of the parasite was confirmed by cultural method). Next day his temperature rose to 104·8°F. and he became drowsy. At this stage we checked the further progress of the infection by a course of atebrin.

Case V.—A healthy volunteer with no history of fever within the past 10 years.

History of inoculations: On 5-5-37 he was inoculated with 4·5 c.c. of blood from a monkey showing a massive infection with *P. knowlesi*. After an incubation period of 9 days he started getting fever. Parasites could not, however, be detected on this date. Fever continued and varied from 101°F. to 104°F. As the infection showed no tendency to die out spontaneously it was arrested by a short course of atebrin. After only two doses (0·1 gramme each) the temperature came down to normal. The parasite count was never high, maximum count being 320 parasites per 1,000 leucocytes. On 1-2-37 he was inoculated with a large dose of *P. knowlesi*, but there was no response.

Case VI.—This case suffered from an attack of malignant tertian malaria and was treated with a full course of atebrin and plasmoquine.

History of inoculation: Five weeks after he had his last dose of combined atebrin and plasmoquine he was given a large dose of *P. knowlesi*. From the 7th day of inoculation his blood films were examined daily for two weeks. As no evidence of infection was noticed he was again inoculated with the same parasite and was kept under observation for a month. During this period he neither showed parasites in the blood nor had he any rise of temperature.

Discussion.

Sinton and Mulligan (1933) have made a series of observations with a number of strains of *P. knowlesi* in connection with their studies in immunity in malaria, and noted that superinfection with a homologous strain of *P. knowlesi* in *S. rhesus* failed to produce a re-infection, and if re-infection was produced its effects were so mild that it could only be recognised by very slight transient increase in the number of parasites in the animal's blood. They have also shown that an infection with one strain does not appear to protect against superinfection with a different strain of the parasite. In reviewing the literature on the subject of superinfection in human malaria, these authors observe that the evidence at present available suggests that the duration of tolerance to re-infection is largely dependent on the continued presence of infecting organisms in the body. For what length of time and in what degree of efficiency this tolerance persists in the human subject after the infection has been cured has not been definitely proved. There is, however, evidence suggesting that in the absence of re-infection after cure the tolerance rapidly diminishes. The experiments recorded above show that an infection with *P. knowlesi* probably confers complete immunity to further inoculation with the parasite (cases I–III). The immunity produced in man following an infection with *P. knowlesi* may be regarded as true immunity and not an 'infection immunity' which is associated with the presence of parasites in the body of the host as is supposed to be the case in human malaria.

Van Rooyen and Pile (1935) pointed out that the individuals who previously received a course of *P. vivax* malaria therapy were resistant to infection with *P. knowlesi*. This observation has also been confirmed by us (case VI). On the other hand a previous infection with *P. knowlesi* does not protect against an infection with human malaria (cases I–V). Three neuro-syphilitics listed above were infected with *P. knowlesi*. Besides, they received one or more attacks of human malaria. Apparently none seemed to derive any appreciable benefit from either form of malaria therapy. It is probable that the malaria suffered by these patients was not sufficient, although one patient ran a course of continued fever for 10 days (*P. knowlesi* infection). Two months later he was again infected with *P. vivax* and the infection was allowed to continue till he had 8 well-marked rigors (case IV). Nicol (Nicol & James, 1933) remarked that on analysing the cases at Horton, it was found that there was a tendency to better results in those cases which had more than 6–8 peaks of fever.

Contrary to the findings of Van Rooyen and Pile we have noticed that infection with *P. knowlesi* is very readily amenable to atebrin (cases IV and V).

Summary and Conclusions.

1. *P. knowlesi* seems to be suitable for the treatment of aged and debilitated individuals owing to the mild nature of the symptoms it produces.

2. As Wassermann positive blood is not suitable for all conditions in which malaria therapy is indicated, the blood of the monkey which is free from syphilitic infection can be safely used for the purpose.

3. An outstanding advantage is the readiness with which the monkey parasite can be maintained in the laboratory by passage from monkey to monkey.

4. A fairly large percentage of cases of infection with *P. knowlesi* has a tendency to spontaneous recovery—the parasites disappearing from the blood and the fever subsiding in a week or so. This mildness of symptoms renders *P. knowlesi* not quite as an effective therapeutic agent as human malaria.

5. Previous infection with human malaria produces a marked degree of tolerance to infection with *P. knowlesi*. Thus in localities where malaria is prevalent *P. knowlesi* does not appear suitable for therapeutic purposes.

6. An infection with *P. knowlesi* does not protect against human malaria.

7. When it is desired to give more than one course of fever to a patient, monkey malaria is of no use, inasmuch as one attack with this parasite seems to confer absolute immunity against a homologous strain of the same parasite.

8. In human infection with *P. knowlesi*, like quartan malaria, the fever may be pretty high even when the parasites are scanty.

9. Monkey malaria in human subjects can be very easily controlled by atebrin and quinine.

10. Neither form of malaria (of human or of monkey origin) seemed to produce any significant beneficial effect on the patient's nerve conditions.

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FORECASTING EPIDEMICS OF MALARIA.

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(Read at Symposium, August 27-28, 1937)

The phenomenon of the occurrence of epidemics followed by periods of quiescence as also of the incidence of epidemic exacerbations in endemic areas is not peculiar to malaria. Forecasting of epidemics has exercised the minds of investigators for many years. Some have given it up as something beyond the possibilities of realization, others have attempted it even though they knew that precise results were not likely to be obtained However, there is no gainsaying the fact that forecasting if successful is of immense value to the practical sanitarian in organizing his resources to meet the situation. It is of equal importance to the epidemiologist who in developing a method of prediction is putting his theoretical principles to a severe test. There are two main principles on which forecasts may be based.

Method 1.—It assumes a more or less complete knowledge of all the factors or at least of the chief factors concerned in the genesis of epidemics and of their interrelationships. Further, it assumes a knowledge of the trend of operation of these factors. If such knowledge were available it would enable one to calculate the result of the interaction of the various processes at any particular time.

Method 2.—It accepts the position that it is not possible to unravel all the causes of the genesis of epidemics, but whatever the force at work may be, one can make use of the recorded experience which when properly manipulated would admit of extrapolation and thus enable one to make a prediction of the future events.

A combination of these methods may also be made use of.

Epidemiology of malaria is a highly complex phenomenon in that here, besides the usual epidemiological factors concerned in the genesis of epidemics, we have to contend with certain special factors, namely the double life-cycle of the parasite and the large number of species of mosquito—a flying insect which acts both as the biological host and the transmitting agent, and in some cases even as reservoir of infection. Ecology of the different species of mosquitoes varies greatly and is subject to modification in certain respects under local conditions. It is therefore not possible to develop any method of forecast which may be of general application.

We are all familiar with the method of forecast which was developed by Gill from his studies on malaria in the Punjab. Malaria forecasts have been regularly prepared according to his method and have been made use of in that

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province for over 16 years. No other province has however so far adopted this system. My excuse for presenting this paper is that as one who has been closely associated with Colonel Gill for many years and who has been responsible for drawing up annual malaria forecasts for a number of years, I think it is an ideal opportunity for inviting a discussion on the subject. Gill's method of forecast is based mainly on the first of the two methods enumerated above, although to a certain extent use has also been made of the second principle.

Gill's main thesis is that the occurrence of epidemics is the necessary sequence of the upsetting of balance between the quantum of infection and the quantum of immunity of the herd in favour of the former.

The principal factors concerned in the quantum theory of infection are :—

(1) The number and distribution of gametocyte carriers as also the intensity of their infection, in other words the size of the reservoir of infection.

(2) The degree of herd resistance.

(3) The number, distribution and habits of the malaria-carrying mosquitoes.

(4) Accessory factors influencing—

(a) the resistance of the community,

(b) the breeding places and the extent of the life of the chief malaria-carrying species,

(c) the development of the sexual cycle of the parasite in the insect, and

(d) the exposure of human beings to the bite of mosquitoes.

Each of these items, I need hardly say, presents a chain of problems about many of which our knowledge is rather scanty. Some of these problems will in fact form the subject-matter of discussion during this symposium and we hope to receive some further light on them. However, the point I want to make is this that besides the fundamental lack of exact knowledge, we have very limited means of collecting the necessary data in actual practice. Moreover, the geographical units for which even these scanty data may be available are too large and perhaps too heterogeneous to admit of detailed study. We cannot, therefore, be too critical about the results that may be achieved from such investigations. We must, however, remember that mathematical studies by Ross and his co-workers by the method of *a priori pathometry* have shown that big upsets in the finely adjusted host parasite balance may be caused by relatively small quantitative changes in the causal factors. Bearing these points in mind we could proceed with a brief discussion of the factors actually made use of in Gill's method of forecast.

1. *The spleen rate of school children taken all over the province in the month of June.*—For purposes of forecast this is intended to provide an index of malaria experience of the community in the previous year and is made use of as a measure of immunity status of the population. It may on the other

hand under certain conditions be interpreted as a measure of the rate of recovery, a high spleen rate indicating low resistance and *vice versa*. Again it may also serve as an estimate of reservoir of infection. The interpretation of the spleen rate in the absence of other relevant information is, therefore, by no means simple

2. *Rainfall.*—Weekly rainfall figures are collected from a large number of recording stations which, though not evenly distributed throughout the province, give fairly good information about the comparative strength of the monsoon in various parts of the province when compared with the normal. These figures are intended to serve as a guide for the estimation of the breeding places of the mosquitoes in different parts of the province. However, for proper interpretation of the rainfall figures a knowledge of the lie of the land is necessary, because there are considerable differences in the efficiency of drainage in different areas and besides there are important differences in the nature of the soil from place to place. A rough index of the significance of rainfall in relation to the incidence of malaria in different districts is provided, as we shall see later by the coefficient of correlation between rainfall and fever mortality.

3. *Economic condition.*—The statements supplied by the Director of Land Records afford an idea of the prevailing economic conditions in different parts of the province. These estimations are taken into consideration in formulating the forecast

4. *Epidemic figure for each thana or town* —This is the index of incidence of epidemic malaria suggested by Christophers It is calculated by dividing the fever mortality for October by the average fever mortality for the months of April, May, June and July of the same year This serves as an index of the incidence of malaria in the locality during the previous year. The centres showing high epidemic figures are not expected to suffer from epidemic malaria in coming years.

5. *The epidemic potential factor* —This is the coefficient of variation of malaria deaths which serves as an index of the possibilities of the occurrence of epidemic malaria in the district—a district with a high figure is, other things being equal, more liable to suffer from epidemic malaria than one with a low epidemic potential factor. This figure is low in areas like Kangra district, where malaria is endemic.

6. *The coefficient of correlation between rainfall and fever deaths for the month of October for the districts.*—These figures are intended to help in interpreting the rainfall figure. In Kangra district the coefficient is negative and high, but in most districts it is positive but varies in value.

In regard to the last three factors it will be seen that the underlying assumption is that the fever mortality figure for October (sometimes the November or even the December figure is taken in place of the October figure if it is high) is a measure of deaths due to malaria. This assumption, I think, is not based on sufficiently convincing evidence. At any rate, the relation of these figures

to the number of attacks is very uncertain. Moreover, for calculating the last two factors areas too big have been taken, which from local knowledge one can say are far from homogeneous with respect to those factors.

Besides these factors information about the localities affected by floods is taken into consideration. The distribution of total rainfall during the two months is also taken into account. If most of the rainfall has been concentrated in a week or so and especially if it has been mainly confined to the earlier period, it is not considered significant even though excess above normal may be fairly high.

Through the courtesy of Dr. M Yacob, Epidemiologist to the Punjab Government, I have received some of the data for the different districts of the Punjab which were used in the preparation of malaria forecast last year A preliminary forecast is issued on the basis of information available by the end of the fourth week of August and the final and more detailed forecast is issued on the 15th September on the basis of full information available up to the end of August. Dr. Yacob's preliminary forecast for 1936 reads as follows :—

'28th August, 1936.'

'A study of the forecasting factors including the available rainfall data up to August 24th does not point to the occurrence of a severe or widespread epidemic of malaria in the Punjab during the ensuing autumn.'

'Localities in which epidemic malaria is mainly expected to occur are the tracts inundated by flood water from the Ravi and Beas rivers and the Bhimbar and Sakki nullahs, namely parts of Sheikhupura, Gurdaspur, Lahore (including the environs of Lahore town), Amritsar and Gujrat districts.'

'Localized epidemic foci of mild intensity are likely to develop in Rohtak district (Sampla and Jhajjar); Gurgaon district (Ferozepur Jhirka, Gurgaon and Ballabgarh); Ambala district (Ambala); Ludhiana district (Samrala), Lahore district (Kasur) and Sialkot district (Daska).'

'The final forecast based on analysis of complete rainfall data up to 31st August will be issued on September 15th, 1936.'

His final forecast was issued in the following terms :—

'15th September, 1936.'

'As a result of a study of rainfall data up to August 31st, 1936, and of other factors concerned in the causation of epidemic malaria the following deductions are drawn :—

1. No major epidemic of malaria is likely to affect the province as a whole during the coming autumn.
2. Epidemic conditions are, however, likely to prevail in parts of Lahore (environs of Lahore town and Kasur); Amritsar, Sheikhupura, Gurdaspur (Batala and Shakargarh), and Gujrat districts.
3. Localized epidemic foci of mild intensity are likely to develop in Rohtak district (Jhajjar and Sampla); Gurgaon district

(Ferozepur Jhirka, Gurgaon and Ballabgarh); Ambala district (Ambala, Kharar and Rupar); Hoshiarpur district (Una, Garhshankar and Hoshiarpur); Jullundur district (Nawanshahar), Ludhiana district (Samrala); Ferozepur district (Zira); Sialkot district (Daska), and Rawalpindi district (Rawalpindi).

4. Throughout other parts of the province, except in tracts flooded by rivers and storm water channels, autumnal malaria incidence is not expected to attain abnormal magnitude '

The previous year's forecast is checked up every year after the epidemic figures have been calculated.

The annual forecast as issued by the Epidemiologist is of considerable assistance to the health officers Perhaps it is possible to further improve the method at present used, but the point I specially wish to emphasize is that personal experience of the conditions obtaining in the province not displayed by these data is an important factor in the preparation of a good forecast.

URBAN MALARIA IN THE UNITED PROVINCES.

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(Read at Symposium, August 27-28, 1937)

The problem of urban malaria is a very large one and it is not possible to review all its aspects in a short paper. Therefore, a brief reference is made to some of the essential factors or features responsible for urban malaria in the United Provinces which are doubtless similar to conditions prevailing in other urban areas of India.

Details of mosquitoes, malarial parasites and figures with regard to spleen rates, etc. have been deliberately avoided as these differ from place to place and are more or less of local interest.

GENERAL REMARKS

The United Provinces is one of the major provinces of India having a population of about 50 millions About one-sixth of the province in the north and north-west, where it is limited by the Himalayas, is hilly and the rest is more or less flat. The province is traversed by six large rivers, three of which, viz. the Ganges, the Jumna and the Sarda, are important with reference to malaria. About half of the province comprised in the so-called Indo-Gangetic plain lies in the basins of the rivers and most of the cities and urban areas are situated in this portion

The average rainfall of the province as a whole is about 40", most of which is derived during the period of the south-west monsoon, i.e. from June to September. The amount of precipitation in the different parts of the province varies from 20" to 80" in the year.

As in other parts of India, the population of the province is largely rural. The urban population comprises only about 10% of the total population and is largely concentrated in about 75 to 80 cities Except the city of Cawnpore, there are practically no other big industrial concerns in the urban areas.

HOUSING CONDITIONS

The more well-to-do and the upper middle classes in the urban areas reside in buildings generally satisfying sanitary requirements But a large section of the population living in the outskirts of the urban areas still live in primitive conditions in bad types of houses or in huts. The centre of a town is usually less malarious than its periphery.

Water Supply and Drainage.

The large cities possess a protected water supply for drinking and domestic purposes, which is derived usually from the rivers or from deep tube-wells. In the case of small towns and notified areas, the water supply is chiefly from the wells. The drainage condition, except in highly developed urban areas, is usually defective and has not kept pace with the growth of the towns.

Vital Statistics.

The crude death-rate per mille is about 25 for the whole province, while that for the towns is about 33. The birth-rate for the province is 36 and for the towns 46 The malarial death-rate for the whole province is about 14, while for the towns it is about 6. The percentage of malarial deaths to total deaths in the whole province is about 70. These figures, as you all know, are not very accurate but they certainly indicate that a large percentage of deaths is attributable to malaria

Urban Malaria

Urban malaria may be broadly divided into two groups as follows. (1) Natural Causes, and (2) Man-made.

1. *Natural Causes*.—(a) This may be due to urban areas growing in the midst of a malarious zone where meteorological and other conditions are favourable for the propagation of malaria. This type of malaria is chiefly noticeable in the cities of the Tarai or the foothill regions which are surrounded by extensive forests and where the rainfall is heavy, viz. Pilibhit, Haldwani, Bareilly and some other towns.

(b) Another natural cause for malaria may be due to the drying up of the rivers on which cities are situated or due to changes in the courses of rivers. An example of this is the town of Moradabad. A portion of the town of Moradabad bordering on the river Ram Ganga became highly malarious, due to the river changing its course, leaving behind a shallow stagnant stream breeding *A. culicifacies* profusely. The solution of this problem was providential as, after a certain number of years, the river returned to its original bed with the result that malaria has practically disappeared now. There are similar examples in other places where towns have become very malarious owing to either the drying up of rivers or changes in the courses of rivers.

(c) Periodical outbreaks of malaria due to excessive rainfall and flooding.

2. *Man-made Malaria*:—(a) Malaria due to proximity to irrigation canals and raising of wet crops, viz sugarcane and rice cultivation.

(b) Malaria due to defective railway systems by blocking up natural drainage or by creating borrow-pits, excavations, etc., which become formidable sources of mosquito breeding. The railway areas of Moradabad, Moghul Sarai, Laksar, Dhampur, etc. are examples of this.

(c) Malaria due to ill-planned cities in which the city grows haphazardly leaving behind excavations, borrow-pits, tanks, etc. without any drainage system.

(d) Malaria due to breeding in wells. This chiefly happens when wells which were once in frequent use are given up due to the introduction of pipe-water supply. *A. stephensi*, a very efficient malaria carrier, finds a very suitable breeding ground in these wells. This has happened in Delhi, Lucknow and Kosi Kalan (a small town near Delhi) and other places.

(e) Malaria due to proximity to big lime and brick kilns and excavations. This type of malaria is chiefly found in the outskirts of towns where the poor population mostly live under insanitary housing conditions close to the breeding grounds.

(f) Malaria due to lack of co-ordination between different bodies responsible for urban sanitation in a particular area, viz Municipal Board, District Board, Cantonment and Railway area, the notified area, Improvement Trust, etc. In such cases what happens is that each department or committee only takes measures in respect of the area under its control without any regard to its neighbouring or immediate area outside its control. It frequently happens that Improvement Trust, Railway or the Cantonments, while improving their own areas, let the drainage of that area flow without any regard into the Municipal or District Board areas.

(g) Malaria may be due to domestic causes. This is chiefly due to breeding in house cellars, chaubachas, garden fountain, garden 'hauzes', broken tins and receptacles, and for this the primary responsibility rests on the house-owners themselves. This is the type of malaria which is least noticed by any community.

(h) Malaria due to ill-developed industrial centres in urban areas. Big mills like sugarcane crushing mills are now cropping up in different parts of the province in proximity to urban areas, and in this connection there is a large wastage of water, which flows into the surrounding low-lying areas and gives rise to mosquito breeding and consequent malaria.

(i) Malaria due to aggregation of labour in urban areas in connection with big engineering projects, viz. canals, roads, railways, etc.

GENERAL.

The urban malaria in the United Provinces is generally of an endemic nature and regional epidemics of malaria which occur in the Punjab periodically are practically unknown. (In the year 1908 some of the western towns of the United Provinces suffered heavily from malaria which was more or less a prolongation of the fulminant epidemic of malaria in the Punjab, and again in the summer of 1929 an epidemic of malaria occurred in the city of Lucknow due to the sudden breeding of *A. culicifacies* in the Gumti river and *A. stephensi* in the wells all over the town.) There is, however, the usual rise of spring

malaria in the endemic cities from March to May when the most prevalent species of parasite is *P. vivax*. During the autumn months from September to November there is a more marked rise in malaria when *P. falciparum* is the predominant species. The distribution of quartan parasites is strictly limited. The principal anopheline mosquitoes found in urban areas are: *A. culicifacies*, *A. annularis*, *A. pallidus*, *A splendidus*, *A. barbirostris*, *A fluviatilis* and *A. subpictus*. Of these *A. culicifacies*, which principally breeds in irrigation channels, river edges, kuchha drains, borrow-pits and tanks, and *A. stephensi*, which chiefly breeds in wells, are the mosquitoes which have been frequently reported as responsible for transmission of malaria in urban areas.

It may be interesting to note that considerable improvements have been effected in certain towns as a result of antimalarial measures, viz. by stopping irrigation, sugarcane and rice cultivation within a 1 mile radius of the outskirts of the municipality. The spleen rate of Saharanpur has fallen from 79% to about 10%. In Moradabad by improvement of drainage and filling borrow-pits the spleen rate has been reduced from 45% to 6·6%. In Nagina by stopping extensive irrigation and draining tanks and filling excavations and borrow-pits, the spleen rate has fallen from 78 to 15%. In this connection it is necessary to stress that malaria investigations and remedial measures should not only be confined to the limits of the urban areas but to an area at least within a mile all round it, so that all the breeding grounds are suitably dealt with as mosquitoes do not respect territorial boundaries. It cannot also be too forcibly impressed that the prevalence of malaria in urban areas to a very large extent is determined by the activities of man, and in many cases is due to a deliberate neglect of elementary sanitary precautions and provisions in town planning or by over-irrigation or increased distribution of water in particular localities.

Urban malaria in most cases is essentially a problem of sound sanitation and can be reduced in most towns and cities in India by co-ordination of activities between different departments concerned for urban sanitation with the co-operation of the public. Suitable antimalarial bye-laws should be made which should be vigorously enforced to achieve any result. If any campaign against malaria in urban areas is to be popular, it must be remembered that the aim, although primarily it should include measures specifically against anopheline mosquitoes, should, however, also include measures against other mosquitoes so that people may immediately appreciate the benefits of an anti-mosquito campaign and thus help in financing the schemes. Further, as funds permit permanent measures should be carried out to reduce the recurring cost on antimalarial measures.

TOPOGRAPHY OF LAND IN RELATION TO MALARIA.

By M. O. T. Iyengar, *B.A., F.Z.S., F.R.S.T.M. & H., Entomologist, Bengal Public Health Department.*

(*Read at Symposium, August 27-28, 1937.*)

Many species of *Anopheles* are specialised in regard to their breeding habitats and are adapted to breed in certain types of breeding places. The distribution would, therefore, be determined by the availability of the type of breeding place suitable for the particular species. Consequently, in a country with different topographical regions, the anopheline fauna shows considerable variation. The species responsible for the transmission of malaria would also differ in the respective regions and the problems connected with the control of malaria would, therefore, differ with the areas concerned.

The province of Bengal, which extends from the Himalayas to the sea, includes different types of country: the mountains, the foot-hill region, the dry undulating area, the deltaic area and the mangrove area. Barring certain species such as *Anopheles subpictus*, *A. vagus*, *A. annularis*, *A. barbirostris* and *A. hyrcanus*, which are more or less widely distributed, the other species have a restricted distribution.

Mountainous area.

The mountainous areas afford little opportunities for mosquito breeding; the nature of the country is such that with the exception of rain pools, small streams and seepages, there are few breeding places. The characteristic anophelines of this region are *A. gigas*, *A. lindesayi*, *A. aitkeni*, *A. willmori* and *A. annandalei*. Other species, such as *A. maculatus* and *A. minimus* found commonly in the foot-hill region lower down, are also occasionally met with. There is very little malaria in the hills because, besides the lack of extensive breeding grounds for *Anopheles* and the sparseness of the species capable of transmitting malaria, the weather conditions, which are temperate, are adverse for the extensive incidence of malarial infection and for the transmission of the infection.

Sub-montane region.

In contrast with the mountainous region, the foot-hill area has a rich anopheline fauna and a high incidence of mosquitoes. Numerous seepages and streams occur in this area which flow continuously for nearly six months in the year. They are fed by the subsoil water in the hills higher up which escapes as seepages and springs in the sub-montane region. These streams form the chief breeding places of the Anophelines in this region which breed

chiefly in running water. The species of *Anopheles* occurring in this area are *A. minimus*, *A. maculatus*, *A. aitkeni*, *A. insulaeflorum*, *A. annandalei*, *A. kochi*, *A. leucosphyrus*, *A. majidi*, *A. jamesi* and *A. karwari*. In addition to these, which are characteristic of this region, we have several other species such as *A. splendidus*, *A tessellatus*, *A. culicifacies* and *A. theobaldi* which are found in the lower regions as well.

This area was at one time extensively covered with a dense tropical rain forest. It has since been cleared of the forest and the land is mostly under tea cultivation. The land is very suitable for tea cultivation as there is a heavy rainfall, the drainage is rapid and the soil is fertile. The high-lying lands are planted with tea while the low-lying marshy areas are cultivated for rice.

The conditions here are favourable for a high incidence of malaria. There occurs an intensive breeding, during the wet season, of species which are highly susceptible to malarial infection in addition to conditions in the human population which are associated with what is known as 'tropical aggregation of labour.'

The clearing of the forest in this region brings about a marked change in the anopheline fauna. In dense forests the species found breeding are *A. aitkeni*, *A. insulaeflorum*, *A. barbirostris* and *A. leucosphyrus* , when the forest is cleared, these species are replaced by species like *A. maculatus* and *A. minimus* which often breed in enormous numbers. These observations suggest that the clearing of the forest brings about a suppression of the forest species, which are not concerned with the transmission of malaria, and offers facilities for the output of harmful species of *Anopheles*

Dry Pastural region.

In this region the rainfall is low. The area is generally undulating with a soil composed of laterite or a mixture of clay and sand. It is traversed by small streams which are dry during summer. There are vast stretches of barren land covered with scrub jungle, dwarfed trees and grassy wastes

The anopheline fauna of this region is different from that of the submontane region. *A. culicifacies* is the predominant species ; others such as *A. theobaldi*, *A. listoni*, *A. pallidus*, *A. stephensi* and *A. splendidus* are characteristic of this region. Wells, which are frequently the source of water supply in this region, breed several species of *Anopheles*, e.g., *A. fluviatilis*, *A. varuna*, *A. culicifacies* and, less frequently, *A stephensi*.

This region has little malaria. The occurrence of malaria is localised in a few areas where greater opportunities are offered for *Anopheles* breeding. Such conditions are produced in different ways. Streams are frequently impounded for irrigation and for water supply. The sides of hills and beds of streams are converted into terraced rice fields. Wells are sunk for water supply. Another factor is the subsidence of land in colliery districts and the interference with the natural drainage. All these factors offer increased facilities for *Anopheles* breeding and thus increase the incidence of malaria.

In this region, areas with a high subsoil water show a higher incidence of malaria than areas with a lower subsoil water level This, as will be seen later, is contrary to what happens in deltaic areas The years with a heavy rainfall have a comparatively higher malaria incidence than years with a low rainfall. In this point also, these dry areas differed from the deltaic areas where the contrary was found to prevail

Deltaic region

This region is the delta formed by the two rivers, the Ganges and the Brahmaputra. It is now traversed by the beds of successive channels into which the Ganges distributed itself from time to time Owing to various causes, many of the channels in the western section of this region have gone into decay while those in the eastern section are alive The latter area is subject to extensive flooding during the rainy season while the western section is not subject to such flooding The main causes for the decay of the channels in the western part of the delta appear to be (1) the silting up of the heads of these channels, (2) obstruction to the overflow of spill water from the rivers by the construction of embankments, and (3) the attempts to keep the rivers to a particular course by the construction of high banks The western region, where the distributaries of the River Ganges are in a moribund condition, has highly endemic malaria while, on the other hand, the eastern section is practically free from malaria.

We find also that in the deltaic region areas with a high subsoil water level have little or no malaria while those with a low subsoil water level are intensely malarious Contrary to what has been observed with regard to the pastural zone, years with heavy rainfall are characterised by a low incidence of malaria while those with a low rainfall have a high malarial incidence

The species of *Anopheles* found in this area are *A stephensi*, *A pallidus*, *A. philippinensis*, *A culicifacies*, *A. varuna*, *A pseudojamesi*, *A tessellatus* and *A. theobaldi*. Species like *A stephensi*, *A culicifacies*, *A pallidus* and *A. philippinensis* are characteristic of the drier parts of the region *A. stephensi* breeds in wells in the dry areas.

Estuarine region

This region is situated on the sea board and consists of a mangrove area subject to flooding by saline tides This region was at one time completely covered with dense mangrove forests but now a large part of it has been cleared of forests and the islands embanked all round to prevent the ingress of saline tides. In areas where such clearing and embanking have not been carried out anophelines do not breed, while in the cleared and embanked areas *A. sundaicus* is very common and causes a high incidence of malaria.

This species of *Anopheles*, although quite characteristic of the mangrove area, has in recent years been observed to invade the interior of the delta. This is evidently due to changes occurring in these areas, and also to facilities

offered in the transport of mosquitoes by boats from the estuarine area into the interior along the river routes.

CONCLUSIONS.

We have seen how in different parts of Bengal the anopheline fauna varies considerably. Although we have a few species which are found all over Bengal, several species have a restricted distribution. This is largely due to the selective habitats of the different species.

These studies also bring out the interesting fact that in several of the regions of Bengal the operations of man are largely responsible for the increased facilities for the breeding of the harmful species of *Anopheles*. In the virgin state, it is probable that the incidence of malaria was comparatively low In many of the regions, the high incidence of malaria is largely the result of human operations. The occurrence of malaria in the sub-montane regions is probably largely due to the extensive forest clearance operations for the purpose of tea and rice cultivation. Thé clearance of the forests have eliminated the harmless species of *Anopheles* and have offered facilities for the intensive breeding of the harmful species. In the pastural region with little or no malaria, the localised foci are the results of attempts to alter the natural conditions, as for example, creating terraced plots for rice cultivation, colliery operations, impounding of rivers and the digging of wells for water supply. In the deltaic area, the construction of embankments to prevent the flooding of the land by rivers in flood or by the tides largely contribute to the establishment of endemic conditions. In the estuarine area, the clearing of the forests and the prevention of the tidal flushing are responsible for the establishment of malarial endemicity through intensive breeding of *A. ludlowi*. In most of the cases these results are due to interference with natural conditions without due precautions being taken against the natural consequences of such interference.

IRRIGATION AND MALARIA [1]

By W. C SWEET, *M D., Dr P H.*

(Read at Symposium, August 27-28, 1937)

Irrigation and malaria have been related terms ever since the health of the people became a subject of governmental and scientific interest and much has been written about it by a long series of eminent malariologists. In a meeting such as this, a review of these previous findings and theories is not necessary so this short paper will concern itself only with those aspects most familiar to the writer, of this broad question of fundamental importance to the future of India

In Mysore irrigation is employed extensively over the greater part of the State on what may be classed as three varying plans First, minor irrigations of small acreage under tanks depending on a capricious rainfall for their water supply , second, larger irrigation projects from greater tanks which seldom or never go dry and distribute water through a fairly extensive system of larger or smaller canals ; third, extensive river irrigations covering a large acreage, with a perennial water supply distributed by large main canals and miles of subsidiary channels. The first type is usually only mildly malarious if at all, the second frequently malarious, and the third invariably malarious Probably the best way to demonstrate these differences is to give a series of spleen indexes in areas representative of the various types of irrigation (*vide* Table 1).

In certain representative areas of Mysore, in which the source of any malaria can be quite definitely limited to one set of conditions, spleen indexes as related to small irrigations vary from 5·3 to 13·2 per cent, whereas in areas with extensive tank irrigations the indexes vary from 11·8 to 89 4 per cent. The riverine systems of irrigation all show high splenic indexes and this is true whether the system is an ancient one, as that around Nagenhalli, more modern as in Hiriyur (Sweet, 1933), or entirely new. There seems no natural tendency for malaria to die out in these riverine systems and, in Mysore, the disease appears as an epidemic immediately after the irrigation water is turned on in new systems. An instance of the epidemic and the endemic malaria conditions produced by new irrigation projects was offered by the Irwin Canal project in the Mandya Area of Mysore.

For some years the Public Works Department of Mysore was occupied in building a dam across the Cauvery River near Mysore City, from which the

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[1] The work here reported was done under the auspices of the Department of Health, Government of Mysore, and The International Health Division of the Rockefeller Foundation.

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TABLE 1

Spleen Indexes in Children in Areas of Mysore State Representative of Various Types of Irrigation.

Area.	Small Irrigation under Tanks.	Large Irrigation under Big Tanks	Riverine Irrigation
Tumkur District—			
Gubbi Area	5·3	.	
Thavarakere	.	54·8	
Kunigal		11·8	.
Chitaldrug District—			
Chellakere Area	13·2		
Jagalur Area	5·6		
Hiriyur			69·9
Kadur District—			
Sakrepatna Area	.	57·6	
Mysore District—			
Mandya Area	9·4		
Yedadore Area			31·8
Chamarajnagar Area .	6·4		
Seringapatam .	.		65·3
Shimoga District—			
Sulekere Area		89·4	
Hassan District—			
Gorur-Arkalgud Area	.		57·9

Irwin Canal was to take water to irrigate some 120,000 acres in the Mandya Area The main canal and three of its branches were completed in 1932 and in June of that year some 50,000 acres received their first supply of water This area had been a comparatively dry one with numerous village tanks under which small irrigated areas existed without producing much malaria, the average spleen index of 33 of these villages being in the neighbourhood of 9·4 per cent before the new irrigation began.

Following the usual methods of irrigation engineers, water was supplied in excess and no provision had been made for drainage so that by the end of the year complaints of malaria began and in 1933 there prevailed an extensive epidemic. Admittedly the reporting of deaths in such rural areas is inaccurate but the reports received and filed are of interest in showing the results of this new experiment in irrigation. Table 2 gives the numbers of deaths in three rural areas in which the great majority of the villages were included in the irrigated acreage and in one area in which less than five per cent of the villages were so situated.

TABLE 2

Numbers of Reported Deaths by Years in Four Rural Areas of Mysore as Related to Riverine Irrigation [1]

Area	1930	1931	1932	1933	1934	1935
Kasaba Hobli— 95% of villages within irrigated area	122	118	280	209	271	378
Dudda and Kothathi Hoblis— 60% of villages within the irrigated area	268	256	375	379	487	308
Basaral Hobli— Less than 5% of villages within irrigated area	96	99	99	90	110	67

Death-rates were not figured for these areas due to the great inaccuracy of the reporting and it would not be wise to compare one area to another too closely, but the general trend of events is well demonstrated by the reports In the Hoblis in which most of the villages were in the irrigated area, the number of reported deaths increased markedly in 1932 to reach a peak in 1933 or 1934, whereas in the adjacent Hobli in which the great majority of villages were not affected by the irrigation the numbers of reported deaths were fairly constant throughout.

The spleen indexes of the 33 villages previously mentioned bear out the picture presented by the reported deaths in that whereas the spleen index averaged 9 4 per cent before irrigation, it was 52·7 per cent in 1933 and 1934 and, in four of the villages which have been studied more thoroughly, was still at 31·7 per cent in April, 1937 That the original epidemic has settled down into what promises to be a permanent endemic condition would seem to be confirmed by this spleen index and the corresponding parasite index of 17·1 per cent in October, 1936

To round out the picture it may be mentioned that blood films showed a great preponderance of *Plasmodium vivax* and that *A. culicifacies* was the only anopheline found carrying, 3·2 per cent of this species showing infection (Nursing, Rao and Sweet, 1934).

DISCUSSION.

Represented in Mysore, then, are three types of irrigation tracts, one of which is mildly malarious, another more heavily so, and the third invariably heavily malarious, the latter riverine type showing not only an initial epidemic

[1] Irrigation water first turned on in June, 1932.

but also a later endemic condition in which there is no natural tendency to diminish even in systems well over a century old. Considering these three types there would seem to be three points which may explain the differences in the malarial conditions found to exist in association with them. These are (1) the length of main and subsidiary channel; (2) the amount of water used; (3) the season of the year in which water is available.

The riverine type of irrigation is characterized by miles of main and subsidiary channels, a feature which never is found in small, village irrigations under tanks, and may or may not be present in the larger tank irrigations. Not only is this dangerous in itself (in places where *A. culicifacies* and members of the *A fluviatilis* group are the carriers), but the malariologist is also concerned with the numerous seepages and overflows from these channels. His problem in this connection is to find some method of preventing the inevitable breeding of the dangerous species in channels and to deal adequately with the seepages.

A striking difference between these three types of irrigation systems is in the amount of water available for use. In the smaller type water is scarce and treated with great respect, whereas in the larger tank system, not so subject to failure due to one bad season, it is more abundant and is found to be wasted to a greater extent. The larger riverine system, however, is pre-eminent in this respect and apparently no attention whatever is paid to conservation or proper use of water in such areas. Water flows continuously in a tremendous over-supply and is found all over the area, very frequently running to waste completely due to the various farming requirements of the cultivators on the branch channel. It seems possible that in this question of the use and waste of water may be a key to the solution of the question of malaria control in irrigated areas. There are always objections to the strict regimentation of the population and the extensive changes in agricultural customs which proper control of water would entail, but in the face of the history of the larger irrigation systems of India there would seem to be no need to hesitate in applying a test of the value of the method, not only for its possibilities in controlling malaria but also in its value to agricultural and monetary returns. Where water is so scarce and valuable as it is in India all interests, including those of the malariologist, would seem to call for its strict conservation.

The third point mentioned, that of the season of the year in which water is available is one which requires more study but in Mysore there would seem to be a quite direct relation between this factor and malaria. Where water is available only during the last six months of the year and all channels and fields are completely dry during the first six months there would seem to be a good chance to escape malaria. The emphasis here must be on the 'completely dry' as in systems in which water is turned into the main channels at intervals during the dry season, as in those in which water is available for cultivation throughout the year, malaria is a great problem. There is still not sufficient known in the tropics about malaria transmission seasons and

much further study is required by the malariologist before a definite statement can be made. However, it must be remembered that over great stretches of India (the parts most likely to be extensively irrigated), the presence of water in the usually hot and extremely dry season might completely reverse the accepted picture of malaria transmission.

The subject cannot be left without mention of drainage, a point in which all irrigation systems are equally lacking. When drainage is suggested the invariable answer is on the score of expense but not providing for the removal of water supplied not only results in lowered financial returns but also in malaria and from both standpoints drainage would seem justified. Just why an extensive irrigation system should be expected to repay its capital cost in a minimum number of years (at the expense of the efficiency of its operation and the health of its people), and in addition give Government a handsome return on its money, is one of those mysteries which ordinary mortals may not fathom.

In conclusion it is of interest to note the existence of a central board for research in irrigation problems of which apparently malaria is not considered to be one for, as far as the writer knows, no malariologist is on this board and malaria enters into its research programme only in a most remote way.

SUMMARY.

There are three types of irrigation systems in Mysore State. One involves a small area under a local tank and is usually not malarious ; a second covers a larger area under a bigger, more permanent tank and is frequently malarious, while the third is an extensive riverine system which is invariably malarious This riverine system not only produces an initial epidemic of malaria, as was demonstrated by a history of events following the opening of the Irwin Canal system in June, 1932, but also is heavily endemic even after over a century of existence. The three types of irrigation seem to differ in (1) the length of main and subsidiary channels ; (2) the amount of water used , (3) the season of the year in which water is available. In these three differences possibilities for the control of malaria exist, special emphasis being laid on the strict control of the amount of water supplied and its use Lack of drainage remains as a defect common to all types but, due to expense, it does not seem likely that this aspect of the prevention and control of malaria in new and existing irrigation systems will receive the attention it deserves until the profit motive is largely removed from consideration.

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SPLEEN AND RESISTANCE TO MALARIA AND HÆMOGLOBINURIA.

By K V. KRISHNAN, *M B., B S., M.R C P , D B., D Sc , Professor of Malariology, All-India Institute of Hygiene and Public Health, Calcutta*

(Read at Symposium, August 27-28, 1937)

The importance of the spleen in the defence mechanism of the body against infections has been fairly extensively studied The mass of evidence that has accumulated shows that in certain infectious diseases the importance of the spleen in resistance is unquestionable while in others it is not quite so pronounced. As regards malaria, although it has long been suspected that the spleen probably plays an important part in resistance to the disease, its exact rôle was not clearly worked out till recently Within the last five years, investigations were conducted on the rôle of the spleen in resistance to *P knowlesi* infection in monkeys chiefly through splenectomy, which is a recognized method of experimental study In order to understand the significance of the results correctly and for purposes of comparison the effect of splenectomy on the course of *L. donovani* infection in monkeys and mice was also studied The results showed that, while splenectomy in monkeys intensifies markedly the course of *P knowlesi* infection and destroys completely both natural and acquired resistance, it has little or no influence on the course of *leishmania* infection in monkeys or mice The following is a brief summary of the results obtained

THE EFFECT OF SPLENECTOMY ON THE NATURAL IMMUNITY OF DIFFERENT SPECIES OF MONKEYS TO HOMOLOGOUS STRAINS OF PLASMODIUM.

The course of *P knowlesi* infection varies greatly in different species of monkeys. Ordinarily in *Silenus rhesus* it causes an acute fatal infection, while in *S irus* and *S radiatus* it produces a low grade, non-fatal infection In splenectomized animals these differences due to natural species immunity completely vanishes, all three species suffer alike from acute and rapidly fatal infections.

EFFECT OF SPLENECTOMY ON THE NATURAL IMMUNITY OF DIFFERENT SPECIES OF MONKEYS TO HETEROLOGOUS STRAINS OF PLASMODIUM.

The host parasite specificity in plasmodium infections is recognized to be fairly rigid and cross infection experiments have generally given negative results. For example, attempts to infect monkeys with the human plasmodium or *vice versa* (except in a few instances) have mostly been unsuccessful. Therefore attempts were made to find out if this natural resistance of monkeys

to heterologous strains of plasmodium could also be broken down by splenectomy. Although seven monkeys were experimented upon (4 *rhesus*, 2 *irus*, and 1 *radiatus*) and two species of malarial parasites (*P. falciparum* and *P. vivax*) were used, none of the animals could be infected even by repeated massive doses of infection. This shows that the natural resistance of monkeys to the human plasmodium is not influenced by splenectomy.

Effect of Splenectomy on Latency.

The usual history of monkeys after infection with *P. knowlesi* and treatment is as follows. The acute primary attack gets cured in about a week and the parasites disappear from the peripheral blood, for a time. Then, for a period of about 4 to 8 weeks, relapses occur to be followed by a long period of latency extending over several months. If splenectomy is done during the latent period of infection, a severe relapse follows. Splenectomy seems to be the best method for inducing a relapse in monkeys in which the infection is latent. Out of 42 monkeys splenectomized during latency 34 relapsed and 8 did not. In the latter, the presumption is that there was no residual infection. The correctness of this supposition was proved by the fact that every one of the 8 monkeys on being given a small dose of *P. knowlesi* developed a severe fatal infection.

Effect of Splenectomy on Acquired Immunity.

It is generally found that monkeys that had once been infected and treated exhibit a certain degree of acquired immunity to re-infection. In some animals this immunity is so great that they cannot be re-infected at all even after repeated massive doses of infection. After the completion of our studies on immunity, there were 11 monkeys that had acquired complete refractoriness to re-infection. Extirpation of the spleens of these immune monkeys resulted in the disappearance of this acquired immunity in all cases. Some of them showed a relapse and the others were proved to be susceptible to re-infection. In the above experiment it is interesting to note that all the *rhesus* monkeys proved to have acquired immunity, relapsed without exception, showing that in the susceptible species the primary infection does not get completely cured and that acquired immunity is associated with the presence of a residual focus of infection, whereas in the resistant species (*irus* and *radiatus*) the infection, in about 50 per cent of cases, gets completely cured and even in the absence of a residual focus of infection a high degree of acquired immunity may be present.

The Effect of Splenectomy on Specific Treatment.

Studies on the value of quinine in the treatment of malaria in splenectomized and non-splenectomized monkeys showed that in splenectomized animals (*a*) larger amounts of quinine were required to cause complete disappearance of all parasites from the peripheral blood, (*b*) the drug had to

be administered for a much longer period, (*c*) the cure rate was distinctly less, and (*d*) the death-rate was markedly higher than in non-splenectomized monkeys. Commencing treatment of primary attack when parasite rate was 10%, 1 gr. of quinine by injection and 4 grs. by mouth per day for 7 days were enough to make all parasites disappear from the peripheral blood in over 80% of non-splenectomized animals. The same treatment in splenectomized animals was able to cause the disappearance of all parasites in 40 per cent of the animals only; but by continuing the treatment for 2 weeks the percentage could be raised to 60

In the case of *irus* and *radiatus* complete sterilization could be effected in over 50% of the non-splenectomized monkeys through efficient treatment with quinine only, whereas in splenectomized animals only 16% could be completely sterilized; others showed a latent infection for a considerable period of time. The death-rate in the treated series for splenectomized *rhesus* varied from 20 to 30 per cent, whereas in the non-splenectomized group it was invariably less than 10 per cent

THE EFFECT OF SPLENECTOMY ON THE INCIDENCE OF HÆMOGLOBINURIA.

Several workers have recorded that hæmoglobinuria occurs as a complication of *P knowlesi* infection in *S rhesus* monkeys in about 30 to 60% of cases and that it does not occur at all in *S. irus* or *S radiatus*. It was found that when the animals are splenectomized prior to infection with *P knowlesi* the incidence of hæmoglobinuria is greatly increased In 90 to 100% of splenectomized *rhesus* and in about 30 to 50% of splenectomized *irus* and *radiatus* hæmoglobinuria is met with. This stresses the importance of the spleen in hæmoglobinuria of monkeys.

THE EFFECT OF SPLENECTOMY ON THE COURSE OF LEISHMANIA INFECTION.

The effect of splenectomy on the course of *leishmania* infection was studied both in mice and in monkeys The normal picture of experimental infection in mice is as follows :—

½ c.c. of a standardized dose of infective material produces in 6 weeks heavy infection in about 20 to 30%, moderate infection in 20 to 30%, mild infection in 20 to 30%, and no demonstrable infection in 10 to 20% Splenectomy before or after infection did not alter this picture in any way.

Four *irus* monkeys infected with *leishmania* were splenectomized This operation failed to affect the course of *leishmania* infection, although the animals were observed for over three months.

From these studies it is concluded that the presence of the spleen plays a part of great importance in the resistance to malaria, but there is no evidence to show that splenectomy influences the course of *leishmania* infection in any way.

PATHOLOGY OF MALARIAL SPLEEN

By M. N. De, M.R.C.P., *Professor of Clinical Medicine, Medical College, Calcutta*

(*Read at Symposium, August 27-28, 1937*)

The spleen is an organ which has been known for a long time past as pre-eminently suited to deal with the effete products which find their way into the blood stream which is thus restored to its original purity. It has also been definitely established that it is one of the most important places in the body where injurious products of all descriptions are effectively dealt with when the latter are brought to it. Furthermore, the spleen has lately gained considerable importance as the principal centre for the production of antibodies which are absolutely important for the defence of the animal body against micro-organismal invasion. For the performance of all the above-mentioned functions, the organ has to depend on certain special groups of cellular elements which form a very characteristic structural unit in the anatomy of the spleen, i.e. the cells of the reticulo-endothelial system. These cells are always available in sufficiently large number to cope with the usual needs of the animal under normal conditions. But under abnormal circumstances either brought about by infection or by the presence of foreign particulate matters resulting therefrom, as in malaria, or introduced into the system by artificial means, as in vital staining, a large amount of extra work is thrown on the spleen which meets the increased demand by putting forth a larger number of its vital cellular elements. Such increased output of cells of the reticulo-endothelial system is only possible because of their enormous potentialities of rapid multiplication and in developing a larger amount of cytoplasm in their bodies. While these cells struggle hard to cope with the abnormal situation, an adequate supply of nourishment, including oxygen, and an equally adequate removal of the products of cellular metabolism must be ensured, and these are brought about by a greater flow both in the arterial and venous systems as well as by dilatation of the existing vascular channels peculiar to the spleen. The net result of all the above changes is an increase in the volume of the organ which is manifested clinically by an enlarged spleen.

It will thus be seen that the essential underlying basis of splenic enlargements, in the majority of cases, is a work hypertrophy to start with modified by such changes as may intervene from time to time under varying circumstances. Such a hypothesis, however, precludes all those conditions where the enlargement is due to gross involvement of the organ by neoplastic and other growths, i.e. lymphosarcoma, lymphadenoma, leukæmia and cystic formations. Coming back to the discussion of the above hypothesis, it may

be seen that all the changes enumerated previously may come upon the organ suddenly but last for a comparatively short period, as in any acute infective process. The resulting enlargement therefore lasts only for a short time and as soon as the infective process is over, the organ gradually resumes its normal size and structure. If, on the other hand, the above factors continue to operate either continuously or repeatedly at frequent intervals, the resulting pathological alterations will *pari passu* not only take place in increasing intensity but will become more or less of a permanent nature. Such splenic enlargements, therefore, do not disappear or take a very long time to do so after the stimulus to activity has ceased to exist.

In such chronic conditions, other factors are superimposed sooner or later and these no doubt are responsible for additional pathological alterations in an already enlarged organ For instance, when the infective process is a long continued one the resulting cellular accumulations in the spleen also become more or less of a permanent nature and these must require some stroma to support them. This demand is met by an increased formation of reticulum which often becomes thickened. Another important feature in these cases is the marked thickening of the capsule and the trabeculæ which therefore, particularly the latter, become very numerous and prominent. In the chronically enlarged spleens, these thickenings consist mainly of fibrous tissue and very little of involuntary muscle fibres. As a result the periodic and rhythmic contractions of the organ are very feeble and the blood in the pulp and sinuses cannot be emptied as efficiently as in a spleen under normal conditions The inevitable result of this change is that the organ remains constantly in a state of turgescence, stretching the capsule and the trabeculæ, which *pari passu* undergo further thickening due to the deposit of additional connective tissue. This high degree of engorgement is noticed during the time of surgical operations for splenectomy when the quantity of blood which may be recovered from the splenic vein, after the organ is removed from the abdomen, may be as much as one-third of the total weight of the spleen. The last but not the least important condition which may supervene is a diffuse fibrosis of the entire parenchyma producing a very hard and tough spleen which cuts with difficulty and with a grating sensation. The pulp cannot be broken down with the tip of the thumb. Such a change results when the poisons brought to the organ work for a long time and are sufficiently strong to cause destruction of the pulp which is subsequently replaced by connective tissue. When this stage is reached, the organ may undergo some diminution in size and its capsule is thrown into wrinkles. For obvious reasons, such a spleen becomes useless to the body.

With a preliminary discussion like the above regarding the pathogenesis of the common enlargements of the spleen, it will be a comparatively simple matter to describe the changes which take place in the organ in the most common tropical malady, viz. malaria.

The pathological changes in the spleen due to malaria will naturally vary according to whether the disease is acute or chronic. In the former condition, which is most characteristically seen in infection by *Plasmodium falciparum*, the spleen is found to be only moderately enlarged. The organ as a whole feels very much distended, its capsule is very tense and it has an intensely dark slaty colour The tension on the capsule is so great that in some very acute pernicious cases I found it as thin as muslin and the slightest pressure of the knife to cut through it led to its rupture Such a stretching and thinning of the capsule in acute malarial infection would explain the occurrence of rupture of the spleen either spontaneously or as a result of trauma of a very trifling character sometimes reported from hyperendemic areas Although when felt over the abdomen during examination of the case clinically, one finds the organ fairly hard in consistence, it is entirely different when the same organ is examined on the autopsy table As soon as the knife is placed on the surface and pressure exerted to cut through the tissues, the stretched capsule almost bursts and the splenic pulp at once bulges out It looks like a soft, diffluent pulpy substance, intensely black in colour with a copious amount of equally dark, almost tarry, blood flowing out of it One peculiarity which must have been noticed by every pathologist having a fair amount of experience of malaria is that it is extremely difficult, almost impossible, to cut a thin slice out of such a spleen as all the pulp tissues being very friable crumble into pieces It is only possible to do so after the organ is hardened and fixed in formalin. When a contact smear of the spleen is stained and examined under the microscope, one finds plenty of red cells, some lymphoid cells, many large phagocytic mononuclear cells laden with hæmozoin pigment and an enormous amount of pigment in large or small masses freely scattered throughout the field. Curiously enough, parasites are found in very small number In one case of which I have a personal knowledge, crescents were found in large numbers but hardly a single parasite in the trophozoit stage could be detected. Probably the infected red cells being damaged by the parasites are readily broken down when the latter are at once destroyed. In the histological picture the most outstanding features are the enormous amount of blood and hæmozoin pigment which have accumulated in the organ. This is so extreme in some cases, that the entire section appears like a mass of blood clot completely hiding the true picture of the spleen Brownish black pigment may be seen strewn all over and mixed with the blood in small granules or in masses and also inside the reticulo-endothelial cells which are found in large numbers. The lymphoid follicles become small in size and are sometimes reduced so much that these can be recognized only in connection with the cross section of the arterioles.

Thus from what we generally see in acute malarial infection it is evident that the enlargement is entirely due to the extra burden suddenly thrown on the organ and to the concomitant vascular changes which inevitably follow such increased output of work.

When the infection is of a chronic nature the changes, though essentially of the same nature, do not present themselves in such an acute form. There is less vascularity but more cellular proliferation with increase in the reticular fibres. The capsule becomes fairly thickened and the trabeculæ get numerous and more prominent The enlargement is always very much more than that in the acute infections but contrary to the usual conception it never assumes an unusually big proportion. In fact if the organ be found to be large enough to reach the pelvis, the suggestion of its being malarial in origin should be revised. I have been forced to arrive at this conclusion after a very careful study of the histological picture of a large series of unselected cases of splenomegaly obtained from the autopsy materials of the Medical College Hospital. The consistence of the chronic malarial spleen is firm and this perhaps is the origin of the term 'aguecake' applied to this type of spleen. During autopsy, the organ cuts well though with a little resistance and the cut surface shows a characteristic appearance, viz. a homogeneous black surface interspersed with minute whitish or greyish streaks. The substance cannot be broken with the pressure of the thumb unless a fair amount of force is exerted. Unlike the spleen in acute malaria one can cut even very thin slices from such an organ The histological picture shows a diffuse pigmentation with marked cellular proliferation consisting mainly of large phagocytic mononuclear cells, their cytoplasm being filled with malarial pigment. There are also many cells of a lymphoid nature particularly aggregated in and around the Malpighian follicles. The vascularity, though obvious, is certainly less marked. Both the capsule and trabeculæ are considerably thickened. When stained with the Foot Bielschowsky's method, the reticulum is found in abundance. This type of splenomegaly which is the result of a chronic repeated malarial infection, although it diminishes in size to some extent, often persists for a very long time, sometimes throughout the greater part of one's life and this is so in spite of all the treatment given to the patient.

The types of splenomegaly described above are always accompanied by varying degrees of hepatic enlargement which is found to be due to the accumulation of pigments in the Kupffer's cells and marked engorgement of the liver capillaries. As in the spleen, these fixed reticulo-endothelial cells not only proliferate in number but also increase in their size. As it takes a very long time to dispose of their load of inert pigments which collect in large amounts, the hepatic enlargement also persists for a long period just like the splenic enlargement. The hepatic cells may contain hæmosiderin granules and also show some degree of fatty change but no hæmozoin pigments are ever found inside their cytoplasm. It must be definitely stated that inflammatory reaction of any kind is not met with in this organ, although in very chronic and long standing infections one may find collections of mononuclear cells limited only to the portal spaces. If we take such cellular accumulations as evidence of irritation, they might produce some fibroblastic reactions in these areas giving rise to thickening of the connective tissues, but even such a change

cannot be found always in the average chronic case of malaria met with in the autopsy room. Such a change, however, can neither produce an appearance of portal cirrhosis nor the clinical phenomena of the common cirrhosis of the liver. The hypothesis of cirrhosis of the liver of malarial origin, although advocated in older times, cannot be supported in view of the histological findings enumerated above.

ANTIMALARIA OPERATIONS IN DELHI.

By M K AFRIDI, *Major, M D, I M S, Assistant Director, Malaria Survey of India*

(*Read at Symposium, August 27-28, 1937*)

The various investigations into the incidence of malaria in Delhi which began with Christophers' survey of Delhi immediately after the great epidemic of 1908 are summarized by Covell (1934) In 1912 Hodgson published a classical report after sixteen months' continuous and exhaustive observations and one far-reaching result of his investigation was that he brought out the extremely malarious character of the site originally selected for New Delhi Apart from that, the adoption of his recommendations regarding the desirability of the closure of the Western Jumna Canal at Lohari Gate resulted in a spectacular reduction of malaria in the City Wards 1 and 2 In 1927, Senior-White carried out another detailed survey lasting one year, but his recommendations were only partially enforced Thereafter, the problem of malaria assumed a backward position and there is nothing special to record except the energetic temporary control measures undertaken by Major Webb in 1929-30 and reports of the officers of the Malaria Survey of India on a few specific malaria problems including abnormally severe spring mosquito nuisances This state of affairs continued till 1936 when in June that year the Government of India undertook to initiate a comprehensive malaria control scheme based on such of the recommendations in the previous surveys as were considered necessary in the light of existing conditions Colonel Covell was placed in charge of the Antimalaria Operations and the speaker was posted under him as Special Antimalaria Officer, Delhi.

Briefly the chief causes of malaria incidence in Delhi are —

1. Excessive canal irrigation, coupled with interference with natural drainage by railway, road, and canal embankments in the North-Western section
2. Annual flooding of the Bela by the Jumna, leading to (*a*) heading up of water in the various storm-water drainage channels, and (*b*) formation of prolific breeding places as the flood recedes
3. Presence of vast numbers of excavations throughout the area in the form of borrow-pits alongside railways and roads, and pits in brick-fields and quarries in the Ridge Area
4. Presence of miscellaneous breeding places, such as temporary water collections around hydrants, ornamental waters, non-mosquito-proof cisterns, wells, and underground storm-water drainage

The measures enforced during the past year may be considered under two headings: (i) permanent measures, and (ii) temporary measures.

Permanent Measures.—The permanent measures have been directed chiefly towards eradicating breeding places caused through faulty storm-water drains, lack of adequate drainage of certain low-lying tracts, and over-irrigation in the area fed by the Western Jumna Canal. These measures can scarcely be looked upon as specifically antimalarial in nature but are rather designed to provide such surroundings for Delhi as can be easily controlled by the antimalaria staff. In securing this objective the activities of the Antimalaria Organization have been intimately linked with those of the Delhi Improvement Trust and other programmes of sanitary improvements. The successful conduct of these measures has been greatly facilitated by the whole-hearted co-operation of the Civil and the Municipal Administrations and of the officers of the Central Public Works Department who have throughout placed all possible facilities at our disposal.

Temporary Measures.—These measures were concerned with the organization of the antimalarial staff of the various municipalities, the provision of oil, paris-green and other larvicides, and the institution of programmes for adequate weeding, minor filling and draining of small temporary collections of water. The central organization for the measures was supplied by the Malaria Survey of India and the striking benefit of such a central control was the elimination of much overlapping of work and the neglect of one sector to the detriment of an adjoining sector. The establishments for different areas have been varied to suit the demands imposed by the climatic requirements and the extent of the breeding sources.

In addition, as an experimental measure, the quarters of certain isolated communities in the Delhi Urban Area were regularly sprayed which have yielded very encouraging results. Similarly the practicability of spraying of paris-green from Aircraft was thoroughly tested, the results of this work were published recently (Covell and Afridi, 1937).

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CONTROL OF ANOPHELINE BREEDING IN IRRIGATION CHANNELS BY PARIS-GREEN

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(*Read at Symposium, August 27-28, 1937*)

The observations in this paper are based on the effect of paris-green on larval breeding in irrigation channels in the Nagenhalli area Describing this area Sweet (1933) has said, 'Practically the whole of Nagenhalli area is under "paddy" cultivation, watered by means of irrigation channels derived from the Cauvery river. The area is, however, too far from the river for it to be a factor in producing malaria-carrying mosquitoes There are two main irrigation channels in the area, one to the south and the other flowing through the northern part Two larger subsidiaries flow through the centre, one forming the southern boundary of Nagenhalli village and flowing on eastward through the farm, the other flowing approximately north and south through the farm. There are of course very numerous smaller channels, running to separate areas of paddy cultivation and between the smaller plots'

Paddy in this area is a winter crop, the first transplantations being made about the beginning of July and the crop being harvested in December. During the active cultivation all the channels run full, but in the summer months, commencing from January to June, water is allowed for the first ten days only in the main and first subsidiary channels As a result of this and the uneven surface of the bed these channels are never completely dry. All the channels are much silted up, with the sides scoured and full of vegetation during the irrigation season, attempts to clean them out being irregular and poorly supervised.

The anophelines reported from this area are :

1. *A aconitus* Donitz, 1902.
2. *A. barbirostris* Van der Wulp, 1884.
3. *A. culicifacies* Giles, 1901.
4. *A. annularis* Van der Wulp, 1884
5. *A. hyrcanus* Van der Wulp
6. *A. jamesii* Theobald, 1901.
7. *A. jeyporiensis* James, 1902.
8. *A. fluviatilis* James, 1902.
9. *A. splendidus* Koidzumi, 1920.
10. *A. pallidus* Theobald.
11. *A. philippinensis* Ludlow, 1902.
12. *A. stephensi* Liston, 1901.

13. *A. subpictus* Grassi, 1899.
14. *A. tessellatus* Theobald, 1901.
15. *A. turkhudi* Liston, 1901.
16. *A. vagus* Donitz, 1902.

Of these 16 anopheline species in the area only two, *A. culicifacies* and *A. fluviatilis*, have been found naturally infected with malaria. An epidemiological study of the relationship of the anophelines of the area to the local malaria problem indicated a definite relationship with the catches of only these two anophelines, *A. culicifacies* and *A fluviatilis* (Sweet, 1933; Sweet and Rao, 1931)

The types of anopheline breeding places in the area are · (1) irrigation channels, big and small; (2) paddy fields; (3) marshy areas where railway and road embankments obstruct natural drainage; and (4) seepage from channels. The irrigation channels offer the largest surface for anopheline breeding and the two malaria-carriers are found in close association and practically confined to these irrigation channels, except that *A. culicifacies* is found breeding outside the channels in paddy fields, marshes, and seepages from the channels With the exception of the paddy fields, where the finding of *A culicifacies* is confined practically to a fortnight or a month in the year (middle of June to middle of July which is a non-transmission season for malaria), the other sources of *A. culicifacies* are negligible The problem of malaria control in the Nagenhalli area, therefore, reduced itself to the control of *A. culicifacies* and *A fluviatilis* breeding in the irrigation channels, the breeding of *A. culicifacies* in the paddy fields being neglected for the reasons explained.

The sections of the channels in the area vary enormously, some are so big as to require spraying from both banks Paris-green has been used in this area as the larvicide since the commencement of control measures in February 1930, but as the road-dust locally available was heavy and difficult to spread in a cloud, ash obtained from a nearby mill was used, in varying proportions with the road-dust, as the diluent, a one per cent mixture of paris-green with the road-dust-ash mixture having been in continuous use from the beginning of the work. The mixture is applied by means of hand blowers and at regular intervals of a week

The effect of paris-green on the anopheline breeding is determined by making larval dips before and after the application of the paris-green mixture The usual practice is to dip for larvæ the same day in the area due to be paris-greened and the area paris-greened on the previous day. Further, weekly adult catches in established catching stations for a fixed time both in the control and comparison villages reflect the effectiveness of the larvicide used.

The larval findings according to their sizes before and after paris-greening for the year 1935 taken as a sample are given in Table 1 below.

TABLE 1.

Statement of larvæ of A. culicifacies and A. fluviatilis found before and after paris-greening for the year 1935.

Stage of Larvæ.	A culicifacies.										A fluviatilis.									
	Before Paris-greening					After Paris-greening					Before.					After.				
	II.	III.	IV	P	Total	II	III	IV.	P.	Total	II	III.	IV	P.	Total	II	III	IV.	P.	Total
January ..	55	31	11		97	34	4			38	52	30	17		99	3	1	.		4
February	183	115	77		375	52	5			57	46	26	30		102	20	3	1		24
March	135	71	37		243	16	3			19	30	13	10		53	2	2	.		4
April .	148	90	60		298	33	7	2		42	25	9	11		45	8	2			10
May	156	97	82		335	36	1			37	35	7	7		49	1				1
June .	137	119	133		389	38	3			41	54	24	18		96	17	1		.	18
July	368	534	532	11	1445	238	70	11		319	116	108	83		307	56	4		.	60
August .	253	249	235		737	144	28	3		175	105	65	73		243	37	3		.	40
September	85	55	60		200	34	3	2		39	26	18	18		62	12				12
October ..	29	25	28		82	12	1	3		16	11	8	6		25	11	2	1		14
November	15	11	8		34					..	18	18	9		45	4	1			5
December	19	8	12	.	39	1	.		.	1	27	13	13		53	8	2	3	.	13

No selection has been made of the figures for any particular year as similar figures are available for all the years the control measures have been in operation. A study of Table 1 brings to light three important facts:

(1) That paris-green is completely effective in killing all fourth stage larvæ.
(2) That its action on the second stage larvæ is negligible.
(3) That a weekly spraying of paris-green is effective in not allowing any of the second stage larvæ to pass through the pupal stage before the next spraying is due.

A study of the adult catches in the catching stations in the control and comparison villages further confirms the effect of paris-green spraying on the anopheline output in the area. The accompanying graphs (figs. 1 and 2) give the monthly catches of the two species *A. culicifacies* and *A. fluviatilis* in the control as well as the comparison villages.

The figures presented in the two graphs cover a period of eight years. During this period, in the first year no antilarval work was done and in the rest of the period the zone of control was varied from a mile, to a half mile, to a quarter mile, and back again to a half mile The catches of *A. culicifacies* (graph 1) during the first twelve months before starting the antilarval work disclose two peaks, one during March, April and May and the other in July and August. The first peak is due to the breeding of *A. culicifacies* in the pools and puddles in the channels mainly, whereas the second bigger peak is due to the breeding in the channels in addition to the breeding in the paddy fields.

It is seen that paris-green spraying has effectively controlled the first peak during the malaria transmission period, whereas its influence on the second peak is limited only to the output from the irrigation channels. That the presence of this large number of *A. culicifacies* during July and August has no influence in this area on the local malaria has been discussed and clearly shown by the downward trend of both the spleen rate and the parasite rate (Sweet and Rao, 1933), subsequent to the antilarval measures.

The effect of varying the control zone on the adult catches in the control and comparison villages is well illustrated. With a one mile and a half mile zone, the comparison villages, situated just outside the half mile zone, were theoretically protected on at least one side from invasion of dangerous anophelines. With the reduction of the control zone to a quarter mile, the disparity in the *A. culicifacies* catches in these two groups is well illustrated. While there is a small rise in the number of *A. culicifacies* catches in the catching stations of the control villages, the rise in the comparison villages is enormous, showing that the partial protection enjoyed with the half mile control zone was completely removed.

A study of the catches of *A. fluviatilis* is further a demonstration of the effective control of this species by paris-green. This species is purely a running water breeder and has at no time been found in the paddy plots. A one per cent

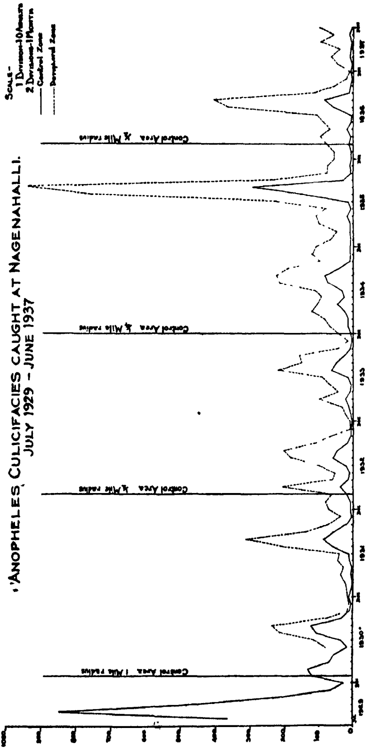
'Anopheles' Culicifacies caught at Nagenahalli.
July 1929 – June 1937
Control Area 1 Mile radius
Control Area ½ Mile radius
Control Area ½ Mile radius
Control Area ½ Mile radius

Fig 1

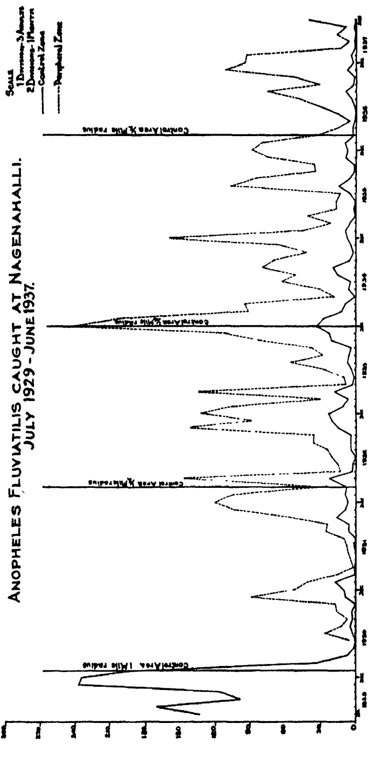
Anopheles Fluviatilis caught at Nagenahalli.
July 1929 - June 1937.

Fig. 2

paris-green mixture has throughout the period kept down the *A fluviatilis* catches in the control villages, whereas the catches of this species in the comparison villages is subject only to seasonal variations.

DISCUSSION

One of the objections to the use of paris-green as a larvicide in antimalaria work has been that, judged by the standard of larval catches, it is not one hundred per cent lethal It is seen from the figures presented in Table 1 that the first and second stage larvæ are almost untouched by paris-green. This is perhaps purely a physical defect in that the size of the particles of paris-green in common use is too big for the larva in the early stages of its growth, but that this is no handicap for effectively controlling anopheline breeding has been amply demonstrated by spraying paris-green mixture once a week (or oftener if necessary), so as to catch these larvæ before they pupate As regards the necessity for controlling anopheline breeding in paddy plots, the experience reported is with reference to local conditions only

SUMMARY

In the light of the studies over a period of eight years in the Nagenhalli area it is possible to conclude ·

1 That paris-green can be effectively used for controlling anopheline breeding in irrigation channels

2. That a one per cent mixture with a suitable inert diluent is a quite adequate strength for use as a larvicide.

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DRUG PROPHYLAXIS IN MALARIA BY THE USE OF QUININE AND PLASMOCHIN IN THE FIELD

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(Read at Symposium, August 27-28, 1937)

INTRODUCTION.

An experiment was carried out during the period 1933–1937 by the Bengal Public Health Department with a view to finding out how far it is possible to control malaria in a hyperendemic area by trying to prevent infection by *Anopheles* mosquitoes by destroying both the sexual and asexual forms of malaria parasites in the human blood by a blanket method of treatment, i.e simultaneous free administration of plasmochin and quinine to the entire population within the selected area, followed by prompt treatment of all malaria cases as soon as they occur. This short memorandum gives the details of the scheme and the results achieved by the experiment.

AREA AND METHOD OF WORK.

The district of Burdwan was selected on account of its high malarial endemicity—the spleen index varies from 60 to 80%. A circular area of approximately 44 sq. units comprising 97 villages with a total population of 21,000 was selected in the Memari thana of the Burdwan district. Children under 12 formed roughly 30% of the total population. The campaign started in April, 1933, with an attempt to treat free of charge everybody within the selected area with a tablet of 0·02 gramme of plasmochin and 15 grains of quinine sulphate or cinchona febrifuge per day for 3 and 5 consecutive days respectively The dosage naturally varied according to the age of the person treated In spite of all propaganda and persuasion roughly about 17% of the population refused to undergo the treatment. The distribution of plasmochin and quinine to the population was carried out by the existing staff of the Public Health Department and was finished by the end of June, 1933. From the first week of July, 1933, thirty treatment centres were opened within the experimental area in charge of six sub-assistant surgeons. In these centres each case of malaria was on the first day of the visit treated with quinine and plasmochin—the daily adult dose being 15 grains of quinine and 0·02 gram of plasmochin for 3 days. On a subsequent visit the patient was given only quinine for another 3 days but no plasmochin. As the attendance of malaria patients decreased considerably by February, 1934, all the treatment centres were closed down and the doctors were detailed to go round the villages in their respective areas and treat malaria cases in their houses. From July to January the treat-

ment centres were kept open again. From March, 1934, 88 voluntary distributors were appointed through whom quinine and plasmochin were distributed in all the villages concerned. The District Board of Burdwan also deputed six sanitary assistants in the same year for a period of 3½ months who did propaganda work and otherwise formed a link between the doctors and the voluntary distributors. Besides the issue of quinine and plasmochin, regular observations regarding spleen index, fever index, parasite index, gametocyte rate, sporozoite rate, etc. were made for which a field laboratory was kept open in charge of an assistant surgeon at Amadpur, within the experimental area, throughout the period under report. To study the variations in the spleen index, thirteen villages within the experimental area were kept under observation, whilst for the purpose of control several villages just outside the experimental area, but with identical physiographical, meteorological and economic conditions, were selected. For purposes of comparison records of dispensaries both within and outside the experimental area have been taken into account

In June, 1936, a departure was made in the system of treatment by issuing to all school children quinine for 7 days and plasmochin for 5 days from the third day of quinine treatment Outside the schools all children and adults with enlarged spleen were given similar treatment with as few omissions as possible The drugs were left with the school-masters and guardians of children with proper instructions To start with, quinine for two days only was issued On the third day, after enquiry as to the fate of the drug already issued, quinine and plasmochin for the next 5 days were given except to those who had refused to take the first issue. By the second week of July, 1936, the distribution of the drugs on the above lines had been completed and thirty treatment centres were again opened as in previous years A modification was also made in treating actual fever cases attending these centres. Quinine was thenceforth given for 7 days and plasmochin for 5 days from the third to the seventh day of quinine treatment. All the treatment centres were discontinued from the 31st January, 1937, and the experiment finally closed on the 31st March, 1937.

As neither time nor space will permit the various observations being given here, only the summary of the results achieved by the experimental scheme as compared with those of the control area is given below :

	1933-34. July-Mar.	1934-35 Apr -Mar.	1935-36 Apr.-Mar	1936-37. Apr.-Mar
1. Malaria incidence in the experimental area (in treatment centres only) ..	6,968	5,967	3,114	2,963
2. Average Fever Index :	Oct.-Nov.	Aug.-Nov.	Aug -Nov	Aug -Nov.
(a) Experimental area .	16·0	12·0	7·5	4 2
(b) Control area ..	42·5	32·2	48·7	25·0

3. Spleen Index:	1933	1934	1935	1936	1937
(a) Experimental area	66·0	not examined		31 4	21 4
(b) Control area	60 5	not examined		65 2	42 9
4. Average Parasitic Index among children	1933	1934	1935	1936	
(a) Experimental area	21 2	22 2	11 0	5 0	
(b) Control area	29·1	30 9	33 9	20 2	

Factors which adversely affected the Result of the Experiment

(i) In spite of all propaganda and persuasion 17 per cent of the population refused to take the medicines The number of Santals in the area is 3,352. They are notoriously backward and aboriginal people who rarely take drugs for any ailment but believe in and practise primitive rituals for curing them from all maladies Apart from these Santals, a small percentage of other people, especially elderly women and babies, could not be persuaded to take the medicines Owing to the custom of purdah among the female folk many women also could not be induced to be examined and properly treated Thus this untreated section remained throughout an active human reservoir of malarial parasites Consequently infection of mosquitoes and dissemination of the disease could not be totally controlled

(ii) Almost all the quacks in a body carried out counter-propaganda against the scheme as they were afraid of losing their daily bread if the experiment became successful

(iii) There was no control against the introduction of fresh infective material in the shape of gametocyte carriers or of infected mosquitoes from outside the area.

(iv) As neither quinine nor plasmochin or a combination of the two can completely sterilize the human host of all parasites or prevent relapses, gametocytes will continue to be formed as long as some parasites remain in the human host in spite of treatment. It is also not known how long a patient will remain gametocyte free after a short course of quinine and plasmochin and thus remain non-infective to mosquitoes.

Eradication of malaria and its control are two very different things Obviously complete eradication of malaria by this scheme is not possible. It certainly reduces the incidence of malaria by curtailing the parasitic factor to a minimum. But how long the incidence of malaria will remain low in the locality in the absence of continued efforts is not known. The recurring expenditure on drugs and distributors cannot be indefinitely maintained.

As a corollary of this experiment it would be interesting and profitable to find out how far anti-larval steps alone without anti-parasitic measures can reduce the incidence in an equally hyperendemic area and at what cost. That either of the measures can reduce malaria is more or less admitted but

which of them is more efficient, less costly and more permanent in effect cannot be proved unless anti-mosquito measures are alone tried in a hyperendemic rural area. Till then we cannot but advocate both the measures together, anti-parasitic and anti-mosquito, to help us in our fight against this principal scourge of Bengal.

FLOOD-FLUSH SCHEMES IN BENGAL

By T A CURRY, *M.Inst C E , M I.E (Ind), Chief Irrigation Engineer, Government of Bengal*

(Read at Symposium, August 27-28, 1937.)

The term ' flood-flushing ' probably needs to be defined in order to understand the object and usefulness of that process Its distinction from ordinary 'irrigation' is also to be noted 'Irrigation' may be defined as ' the introduction of water on to land by artificial means for the purpose of watering the crops grown thereon '.

Accordingly, the amount of water so introduced is regulated by the requirements of the crop to be irrigated, and it is the constant aim of the Irrigation Engineer to so perfect the method and arrangements for the distribution of water that as large an area of cultivation as possible may be efficiently served with the supply available As a general rule a depth of watering of 2½ inches to 3 inches is given, and such waterings are repeated at intervals of about 10 days until the requirements of the crop have been met Taking one cubic feet of water per second, commonly known as ' one cusec ', as the unit of discharge, an area of 79 acres can be inundated to a depth of 3 inches by one ' cusec ' in a period of ten days ' Flood-flushing ', on the other hand, aims at introducing water on to land for the sanitary improvement of the area flushed as well as for the revitalizing of the land and the irrigation of the crops grown thereon

As its name implies, flood-flushing can only be carried out during the flood season when the rivers are heavily silt-charged and full to overflowing, and there is no anxiety about the adequacy of the supply available, and the only limits to the discharge that is to be passed on to the land are those imposed by the survival of the crops, the capacity of the drainages and the safety of buildings, and culverts, etc.

Bengal is a deltaic province and one of the principal functions of its rivers is to spill, during the flood season when their waters are heavily charged with silt, over the surrounding land.

If the natural conditions are allowed to prevail the lowlands traversed by deltaic rivers are gradually raised to above flooding level by the recurring deposition of silt and sand thereon from the spill of the rivers.

It would take too long to go in detail into the process of land reclamation by delta-building rivers and of the harmful results that follow interference with such natural action, suffice it to say that during the process of raising the level of the land the swamps, and low areas generally, are refreshed for

several months annually, and the land spilled over is raised and rendered fertile for cultivation.

In Bengal, owing to the economic needs of a rapidly increasing population, embankments to prevent many of its rivers overflowing their banks have been erected. At first the results of such action were very profitable, crops were grown without risk of ruin by flooding, railways, roads, factories, and all the other amenities and accompaniments of material and industrial progress were introduced. Later, however, the harmful effects of the policy of embankments began to be felt. When a river is embanked the silt, which is intended by Nature to be discharged on to the surrounding lands, cannot escape from the river channel and is mostly deposited on the bed, thus choking the channel and causing the bed level to rise. As the bed level rises the water level also rises and, in consequence, the embankments have also to be raised to keep pace with the rise in the bed and water levels of the river The lowlands remain at the same levels and so unhealthy swamps are formed which cannot be drained and become a menace to public health ; the lands, which would normally be revitalized and moistened by river spill, become infertile and the natural system of surface drainage becomes upset Owing to the rise in the river levels the danger of breaches in the embankments and of disastrous flooding of large areas becomes ever present.

The contrast between the conditions in East Bengal and Central Bengal is very striking. In the former (except in a few areas where embankments along rivers have been constructed) the countryside is subject to river spill and is fertile and populated by a virile and healthy population.

In Central Bengal where the rivers have been embanked, all the harmful effects mentioned above are evident. The rural population is declining and has become debilitated by malaria and other diseases, and agricultural prosperity has decreased. The remarks made in the foregoing paragraphs are not intended as a criticism of former engineers. Embankments in similar circumstances are still being erected in other countries, the most recent example being along the rivers Axios and Aliakmon in Greece to prevent them spilling over the Salonika plain.[1]

Of course, farmers and their lands that have been accustomed to the protection of embankments cannot suddenly be exposed to the fury of flooded rivers. Nevertheless, it is the declared policy of the Irrigation Department in Bengal to slowly abolish embankments wherever possible and to prevent the erection of any fresh embankments.

In addition, following the activities and investigations of medical scientists like Dr. Bentley and Rai Bahadur Dr G. C. Chatterjee a policy of flood-flushing has been initiated. Those workers have shown that, apart from the beneficial effect on the productivity of the soil and the gradual raising of low

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[1] *Vide* a paper by B. W. Huntsman, B.Sc., M Inst.C.E., read at the Institution of Engineers, London, on the 26th January, 1937.

areas, the passage of silt-laden water over agricultural lands has a marked beneficial effect on the public health of the locality concerned As far as it can be understood by a layman the propagation of mosquitoes in hollows in the land is interrupted, while the tanks and swamps are refreshed, and there again the breeding of mosquitoes is interfered with by the introduction of silt-laden water and of carp fry which are carried in suspension by the flushing water and which soon grow into vigorous larvæ-devouring fish

The conditions that prevail in East Bengal and those ruling after the otherwise disastrous breaching of the Damodar river embankment in 1913 and again in 1935 left no room for doubt that the theories propounded by the workers named are correct. So a beginning was made, in a small way, with flood-flushing schemes in different parts of the province Thus the highly malarial village areas of Pingla, Naraingarh and Kola in the district of Midnapore, covering an area of 8,278 acres including 729 tanks, have been flushed with water from the Cossye and Rupnarain rivers through the Midnapore canal system, free of charge to the villagers, during the flood seasons of 1932 to date.

The inhabitants there are kept under medical observation by the authorities of the Public Health Department, and the reports show a marked improvement in public health as evidenced by reduced treatment at dispensaries for malaria and other fevers and by a reduced spleen index The results of the introduction in 1934 of flood water (free of water tax) from the Gobra Nullah on to the lands of the villages of Maidyagobindpur, Madapur, Bahadurpur, Sultanpur and others in the Murshidabad district, were even more striking for whole village sites which had been abandoned on account of malaria were reoccupied Seven thousand one hundred and twenty acres were flushed and the report shows that in addition to reducing malaria the yield of the *aman* paddy crop was approximately doubled and grubs and insects like white ants were destroyed. Again, with the aid of the Collectors of the Jessore and Nadia districts, it is hoped to throw open to river spill, from the Mathabhanga river and its distributary channels, considerable areas where unhealthy conditions at present prevail

The area of land between the lower reaches of the rivers Damodar and Hooghly is one where unhealthy conditions prevail and where the productivity of the soil is now much less than in former days, in consequence of the presence of the embankment along the left bank of the river Damodar. Encouraged by the success of the trial measures mentioned above, and acting on the suggestions put forward by the Public Health Department and by the Rural Development Commission of Bengal, an ambitious scheme has been submitted to the Local Government for flushing 3,50,000 acres, in the districts of Burdwan, Hooghly and Howrah, between the Damodar and Hooghly rivers, by the flood waters of the Damodar river at a cost of Rs 273 lakhs = (£2,100,000). The salient features of the scheme include a barrage in the river Damodar near Burdwan and a network of distributing channels fitted with regulators,

capable of carrying 13,160 cusecs (a discharge equal to the normal flood discharge of the Thames river at Staines), and adequate sluices for the drainage of the excess water into the river Hooghly.

SURFACE AND SUBSOIL DRAINAGE.

By F C GRIFFIN, *Chief Engineer, Public Health Department, Government of Bengal.*

(*Read at Symposium, August 27-28, 1937*)

The general principles affecting the relation between the control of water and malaria prevention are now well known. They may be re-stated as follows —

(1) Mosquitoes breed as a rule around the *edge* of water,—out in the middle of a large tank or lake the surface movement is too great

(2) Most of the malaria-carrying anophelines prefer *clear* water, not necessarily stagnant water.

(3) Mosquitoes cannot breed in water which is heavily laden with silt

(4) A number of varieties of small fish feed on mosquito larvæ, so that a good-sized tank, well stocked with fish, and with sides kept clear of weeds, can be considered as practically non-malarious

It is obvious that the simplest way to prevent mosquito breeding in a particular area is to drain away all water from that area. The ease with which this can be done depends however on natural conditions,—and my note is divided into two main parts,—the first part being with regard to areas where drainage is comparatively easy and the second with regard to areas where it is difficult, owing to conditions being against natural drainage

Easy drainage applies of course to land where there are sufficient differences in level and where the water can run off down the natural slopes, and a very moderate amount of slope can be made sufficient for this purpose It is surprising how effective natural surface drainage can be made even in a comparatively flat country, when the ground is accurately graded and the water channels are carefully trimmed to exact slopes, as is the case with the Calcutta Maidan.

Practically the whole of the land has its natural surface drainage,—formed by the rain water in its endeavour to pass down to the sea. Stagnation of surface drainage is sometimes due to natural occurrences such as landslides or earthquakes, but is more often due to man's interference with natural conditions. The establishment or restoration of good drainage therefore amounts to an investigation as to what are,—or should be,—the natural drainage channels, and the construction of means for overcoming any obstructions that may be in the way. Among the various ways in which man's

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interference with nature has caused drainage obstruction, the following may be mentioned :—

(1) Encroachments on drainage channels,—either by building over them, or too close to them—thereby confining the channel in too small a width.

(2) Obstruction of drainage channels by throwing into them rubbish, earth, or filth.

(3) By putting fishing weirs across drainage channels and failing to remove them again when the fishing is done.

(4) The construction of embankments for roads, railways, or canals, without making sufficient provision for the natural surface drainage.

(5) Paddy field terracing.

(6) Mining subsidence. The results of mining operations in many places have been to cause the surface of the ground to cave in, with the result that water stagnates in pools and the gradients of surface channels are interfered with.

Other more general points might be mentioned, such as denudation of forest land. When the forests are cut and no re-planting is done, the exposed soil moves more quickly down the slopes to the stream in the valley below, sometimes through landslides The soil comes down more quickly than the stream can carry it away, and accumulations here and there tend to hold up the drainage in the valley. Also the extra volumes of soil and stones which *are* carried away by the streams block up the rivers lower down in the plains, and accentuate the drainage difficulties there

Where there are good natural slopes, the improvement of drainage should be simple. Encroachments can be pushed back and the drains kept sacrosanct Rubbish must be cleared away and arrangements made for keeping the drains clean By proper grading of channels and continuing them to suitable outfalls, it is generally easy to get good drainage

One of the experimental antimalarial schemes carried out by the Bengal Public Health Department in 1917 was in connection with colliery land near Raniganj. Here the land had been tumbled about by mining subsidence, and in one place there was a level swamp. The engineering work done consisted of re-grading the natural surface channels, putting in culverts where embankments were obstructing drainage, and in draining the swamp by means of a network of sub-drains. These consisted of earthenware pipes, laid open jointed in a bed of gravel and broken stone. There was a main sub-drain, and branch drains in herringbone fashion. Of course careful levels were taken to shew that there would be a proper outlet for the main sub-drain The drain at its outlet end was about 4 feet below ground, but there was a lower level channel into which it could discharge.

Subsoil drainage is practised in many parts of the world,—perhaps more for agriculture than for antimalarial purposes. Machines are available which construct a rough sub-drain at great speed. More often the 'agricultural tile' is used,—a rough earthenware pipe, without socket, 3 or 4" in diameter, and laid end to end without any joint. The water finds its way in through the abutting ends of the pipes. Of course it is all important that such a drain should be laid with the proper amount of slope,—a 4" pipe should have a slope of not less than 1 in 60.

An interesting form of sub-drain was constructed in connection with the antimalarial scheme at the Meenglas Tea Estate, in the Duars. This estate is traversed by a number of streams (*jhoras*), and there is a good natural slope from north to south. As the anophelines were breeding along the edge of the running water, it was decided to put the streams underground by means of sub-drains. The long distance for transport would have made earthenware pipes expensive, and as plenty of stone was available at the site, it was decided to make the sub-drains of stone. A stone bed was laid to a continuous gradient, side walls of dressed stone were built on it, and big stone slabs laid across the top,—the whole being then filled in with small stones up to the natural bed of the *jhora*. The side walls and top stones were laid without mortar so that water finds its way into the drain through the crevices of the stonework. One or two lengths of small drains were done with pipes, so as to make a comparison in cost. The cost of a sub-drain 9" wide and one foot high worked out at 7 annas 6 pies per foot run.

The areas where drainage is difficult are of course those areas where there is insufficient natural slope. In the low-lying parts of flat country like the deltaic areas of Bengal water *must* lodge during the rainy season, and often,—as far as malaria is concerned,—it is found better not to attempt drainage, but to bring in river water so as to *raise* the general level and thereby reduce the amount of edge round which the mosquitoes breed. Hence the "flood-flush" drainage schemes. Good results have been obtained by the application of this principle. With the river water, silt and fish are brought into the channels, ditches and tanks, and these are inimical to mosquito breeding. Also the silt helps in the gradual building up of lowland, and the fish, when developed in the tanks, form a useful article of diet. Of course the connection with the river is controlled by a sluice, so that in case of extraordinary high flood in the river, the flow in the flood-flush channel can be restrained so as to avoid damage to property from excessive flooding. An alternative to flood-flushing in low-lying areas is the application of power for pumping off the water. In urban areas, where the surface water must be removed from the vicinity of habitations, underground sewerage systems are constructed. These, with their pumping stations, of course are expensive. As a rule they do not come within the range of practical politics unless they serve a double purpose, i.e. the conservancy system of the town must be dealt with in addition to the drainage of low-lying areas. But the possibilities of removal of surplus water

by means of simple surface drains and modern types of pumps must not be overlooked. When cheap electric power is available, as in the Calcutta area, neither the capital nor running cost is high. A low level tank can be constructed or an existing tank or series of tanks can be made use of to act as a storage reservoir to receive the water from the land to be drained, and by means of a pump of moderate size and cost, the water can be pumped away at leisure. An example of this can be seen at the Jodhpur golf course, where a pump driven by a 4 horse-power motor deals satisfactorily with an area of 80 acres. The power required for the pump is so small, because, the height through which the water is lifted is only six feet.

In a deltaic area, the land near the river-bank is above flood level, while further away from the river it is below flood level. It follows that there is a natural line,—roughly parallel with the river, and at a certain distance from it, such that, between the line and the river the policy of land raising and natural surface drainage should be pursued. Within that area excavations should be discouraged. If there were no small tanks and ditches in that area, there would be very little mosquito breeding On the other side of the line, the digging of tanks, excavations for brickworks, and other works to provide earth for filling purposes, may be allowed,—for, during the flood season, the low ground will become one sheet of water and there will be no mosquito-breeding edge

PHYSICAL FACTORS IN MOSQUITO ECOLOGY

By R. SENIOR-WHITE, *F R.S.E*, *F.R E S.*, *F R S T M & H*, *M R San I*, *Malariologist, B N Railway*

(Read at Symposium, August 27-28, 1937)

Whilst it has been the common experience of all field workers on Malaria from the original investigations of Stephens and Christophers (1902) that the various species of *Anopheles* have different breeding places, and that in one single breeding place a succession of species mav be found at various seasons, the chemical and physical factors that cause such phenomena were not investigated until the pioneer work of MacGregor (1921) on the influence of hydrogen-ion concentration His preliminary conclusions were that *A maculipennis* became diseased in acid waters The same author (MacGregor, 1924) continued his English observations in Mauritius, and reached the generalization that Anophelines are alkaliphiles, and Culicines acidiphiles In the same year Buxton (1924), on a third Anopheline Fauna, that of Palestine, found six species, all in alkaline water The present author (Senior-White, 1926) published the first really long series of larval-pH findings, made in Ceylon, finding that, though for each species there appeared to be an optimum value, the range found for the majority was very wide, almost, in fact, that of the whole series of waters examined The conclusion reached was that only extremes, both of acidity and alkalinity, are inhibitory to breeding But, from an investigation of the 'residual pH', that is the value after expelling CO_2 by shaking or boiling, it was found that, for Anophelines at least, acidity other than that due to CO_2 is definitely inhibitory. The first conclusion, that only extremes of 'actual' pH have any inhibitory effect, was confirmed by experimental work by Buxton (1927) Later, in East Central India and at Delhi, it was shown (Senior-White, 1928) that nine species common to Ceylon, East Central India and Delhi exhibited very different toleration limits and even optima in these three areas, and that therefore pH *per se* was not the controlling factor in making water suitable or otherwise to various species of *Anopheles*.

MacGregor (1929) summed up all work on this factor to early 1928, and made careful laboratory experiments. His conclusions are '(*a*) if the pH of the normal environment is changed the development of the larvæ is adversely affected: (*b*) this statement is not true under bacteriologically sterile conditions: (*c*) consequently the acid or alkaline reaction of the medium, within ordinary limits, has no direct effect on the development of the larvæ' He concludes that 'pH is of unquestionable importance.. . . ... .in. .... that..........it indicates the favourable or unfavourable association of chemical and biological factors in the breeding places.'

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Thus pH is no more than an 'indicator', and other factors have to be evaluated.

The study of other chemical water factors had been commenced in 1922 by Lamborn (1922) in Malaya, using a few analyses performed for him on nine measurable factors, from which he was unable to deduce any certain conclusions. Purdy (1925) failed to obtain larval correlations with pH, dissolved oxygen or mineral solutes. Hacker (1923) was able to correlate the abundance of two species, one a vector and the other harmless, with the albuminoid content of the waters, the carrier being most common in the presence of low values, the non-carrier of the opposite.

The present author took up the study of various chemical factors in addition to pH (Senior-White, 1926), measuring dissolved oxygen, mineral solutes (by conductivity) and saline ammonia It was shown that high dissolved oxygen content appeared to favour the use of natural waters by Anophelines, and that this was especially important in rice fields, but the principal discovery announced was that *saline ammonia in amounts of less than 1 p p m was inhibitory to natural water breeders*, especially Anophelines In a later communication (Senior-White, 1928), in addition to pH, the following factors were studied and shown to be of no value in controlling breeding —Conductivity, carbonates and albuminoid ammonia. Residual pH and dissolved oxygen after further work may still be studied in the hope that they will yield results of value Phosphates in fresh water appear to be much less important than they are in sea water, but are worth further study. The conclusions formerly arrived at with regard to saline ammonia were confirmed for three vector species studied but not for the non-carrier *subpictus*. This value has since been confirmed by Beattie (1932)* for a Neotropical species, which shows this criterion is the only one of importance so far discovered Whether it is applicable to all the 170 known species of the genus *Anopheles* is, however, quite another matter, still uninvestigated. The factor is not, however, a real one. It cannot be repeated in the laboratory, where larvæ can withstand far higher concentrations (up to 100 times) of various ammonium salts than the natural limit. An old paper by Waddell (1902) was found, in which 250 p.p.m of *liquor ammoniæ* were found to be fatal to mature larvæ But such concentrations are quite unlikely to occur in Nature. The factor, therefore, that we measure as saline ammonia must be only one in some way correlated with NH4, and not that ion itself.

Williamson (1928) took this investigation a step further, and showed that the inhibitory effect was obtained when the relationship $\frac{\text{oxydised}}{\text{ammoniacal}}$ N$<$1. This suggests that the process at work is probably bacteriological, and so would explain how it is that the dissolved oxygen content appears to have

* Buxton's (1934) analysis of this author's findings should be studied *pari passu* with the original paper.

some connection with mosquito breeding, though Iyengar (1929) failed to trace much connection. On the other hand Bekhemlishev and Mitrophanova (1926) state that an optimal breeding place is characterized by oxygen saturation or supersaturation and a basic reaction, though they are without 'immediate' vital importance to the larvæ. I think the Russian authors, by 'immediate' mean 'direct'. The quotation is from their own English summary

Beattie (1930) repeated in England the methods of earlier workers abroad She failed to obtain any correlation with saline ammonia, but her findings for this factor were never in excess of 0 6 p p m She considered that pH, H_2S, total organic nitrogen and dissolved oxygen had some bearing on the incidence of *maculipennis* and *bifurcatus*, but her results are not very convincing

An entirely new line of work was opened up in 1932 by Hinman (1932) and (1932A), who showed that Anopheline larvæ could utilize material in solution and colloids in suspension in Seitz-Werke filtered water, but not in the dialysate from such water He refers to amino-acids and monosaccharides particularly This was independently worked at by Shipitsina (1930) Both authors seem to have been following the still unproved theory of Pütter (1911) regarding the alimentation of marine organisms In this connection Hinman (1932B) has studied the enzymes of the digestive tract of larvæ, finding amylase, invertase, (sucrose) xylanase and a protease acting in alkaline medium Negative results were obtained for maltase, lactase and an acid medium protease This work was done with Culicines and not Anophelines. He points out that his protease finding is in accordance with my work on the pH of the intestinal tract, done with Anopheline larvæ (Senior-White, 1926) as well as Culicines

Morin and Bader (1933) were the next in the field They found that the ratio $\frac{\text{free}+\text{half bound}}{\text{total alkalinity}}CO_2>1$ in water that was breeding Anophelines They developed this thesis further the following year (Morin and Bader, 1934), and pointed out that upward seepage through clay at certain seasons permits of the breeding of various species normally confined to springs and the upper reaches of rivulets, but they have so far failed to pursue the matter further. The authors have, however, definitely 'got something' out of a factor in which I (Senior-White, 1928) had failed to find anything of significance

The present position has been summed up by Williamson (1936), in a publication which must be consulted by anyone interested in the subject. According to the later work of this author (Williamson, 1936A) it would now appear that it is not so much the water itself, as the underlying soil, which determines whether malarial vectors do or do not breed in the water Excess albuminoid nitrogen in the presence of deficient oxidation characterizes non-malarial soil. Below a soil nitrogen content of 0 1%, malaria is to be expected from standing surface water. at levels much above 0 3%, stagnant, shallow waters are inimical to all Anophelines. A high degree of nitrification, giving

a high ratio of nitrate to ammoniacal nitrogen, indicates adequate oxidation and is compatible with the breeding of malaria carrying Anophelines.

Thus the studies of single factors, which have yielded by no means conclusive results, as has been shown, have, through the genius of Williamson, been combined into a compound factor made of the interaction of ammonia and oxygen which has not only immensely clarified the problem, but opened up the way to 'naturalistic' methods of malaria control, the secret of which, in many instances, is seen to be better agriculture, raising the soil nitrogen content.

That author's 'herbage cover' method of stream control, recently shown by myself (Senior-White, 1936) to have great possibilities, is another method of producing excess albuminoid nitrogen in the presence of deficient oxygenation.

It has long been apparent to all workers that chemical larvicides have a most limited application owing to their excessive cost, and are, in fact, quite unsuited to the vast rural tracts of this and other Tropical Countries Cheaper methods will have to be evolved if anything is to be done for rural malaria generally. We now see that by further work on the points so far discovered the method can be envisaged from afar, by improving the standard of agriculture by soil enrichment, a method which will doubly benefit the villager by raising his standard of living. We come to purely agricultural methods as our main weapon of attack, the raising of fodder crops, the stabulation of cattle, the conservation of cow-dung for manure instead of its wasteful expenditure as fuel. These are questions for the agriculturist and the economist rather than the malariologist, who can only strengthen the hands of these professions by pointing out that success in their immediate object will, in time, lead to the control of the 'King of Tropical Diseases'.

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ANOPHELES LUDLOWII (*A. SUNDAICUS*) SURVEY IN AND AROUND CALCUTTA

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(*Read at Symposium, August 27-28, 1937*)

Introduction

The earlier records of *Anopheles ludlowii* (Theo) from Bengal was that of *Anopheles sundaicus* (Rodenw), as we know now, and is regarded as the correct name for this mosquito as already pointed out by Covell (1932) It has received so much publicity by its former name of *ludlowii* which, although not accepted by recent authorities, is still used in official records as the name is better understood by local bodies. The species *Anopheles sundaicus* normally breeds in water containing salt in various concentrations, and is a virulent carrier of malaria In Bengal it has long been known as a coastal species, being mainly restricted to the Sundarbans, but within the last six years the breeding of the species has been more and more intense in the inland areas. Thus, barring the exceptional record by Brahmachari of the species breeding temporarily in the Campbell Hospital tank within Calcutta in 1912, this mosquito was not known to have established itself anywhere nearer to Calcutta than Port Canning on the Matla River about 28 miles from the city prior to 1930, when for the first time the species was recorded by Iyengar (1931) from Budge-Budge and Chengail, both being situated on the River Hooghly but on opposite banks and within 18 miles of Calcutta This invasion in 1930 caused a heavy outbreak of malaria in both Budge-Budge (the spleen rate rising as high as 91% in some places) and Chengail (the spleen rate jumping to 74% in the worst places) A natural apprehension was felt that, should the species spread further northwards and ever establish itself in the Salt Lake area east of the city, the health and prosperity of Calcutta would be endangered. The then Director of Public Health, Bengal, therefore advised the Local Government that a detailed investigation was necessary in order to trace the distribution of the species along the various tidal rivers and swamps in the neighbourhood of Calcutta. As a result of this move, a systematic survey has been made to locate the breeding places of the species since 1931. The survey reports prepared by me and my colleagues from time to time have been utilized by Senior-White (1937) in compiling the distribution of the species in a very recent paper.

Distribution of the Species in Lower Bengal.

Almost from the very beginning *Anopheles* (*ludlowii*) *sundaicus* survey work has been proceeding along two distinct lines, (1) the river-side areas

including the places served by the rivers Hooghly, Bidyadhari, Ichhamati and the various channels leading from these, and (2) the Salt Lake areas to the east of the city including the fringe areas of Calcutta. There are several railway systems intersecting the river-side areas and the survey parties were despatched along each of these lines in successive periods almost regularly.

River-side Areas.

The first evidence of the prevalence of the species in other areas outside Budge-Budge and Chengail along the River Hooghly was discovered in June 1931, almost immediately after the commencement of the present investigation, when the species was recovered from Falta (spleen rate 12·5) proper and about a dozen villages surrounding it in the lower reaches of the River Hooghly on the same bank as Budge-Budge At the same time a large number of infected adults of the species was detected as being transported through K.F. Ry. trains to Majerhat, a little beyond Alipore from this zone. The Falta focus extended to Shivanipur, Sirakole and finally to Bishnupur about 10 miles away in 1934. The upper limit of the species along the left bank of the river appears to be Shamnagar which is 19 miles away, where the species in its winged form occurred as far back as 1930 (Iyengar, Covell), but the breeding in this area could not be traced until 1933. The same year adults of the species were found in Pujali and Mayapur,[1] a place of commercial importance nearly 5 miles south of Budge-Budge, which was under the effective control of the Government anti-*ludlowii* staff and the spleen rate to-day has come down to 2 6 only. A little further down a fresh focus appeared in 1934 at Godakhali almost half-way between Falta and Budge-Budge, thus by 1934 the whole tract between Falta and Budge-Budge being involved.

The species was not quiescent in the upper reaches of the River Hooghly, and surveying above Calcutta it was found to be breeding in 1933 in Dakshineswar not far from Calcutta, being within 9 miles, and having direct communication with the city by bus and steamer services There was some lull after this, and it was only in 1935 that active dispersal of the species took place along the upper reaches, when Cossipur (Sinthi), Dum-Dum which is within 5 miles (spleen rate 10·0 to 13 0), Khardah (12 miles) and Ichhapur (17 miles), all very important industrial areas, were infested with the species The same year adults were caught at Chitpur Lock Gate within Calcutta near Baghbazar. Panihati and Sodepur (10 miles away) showed some breeding in 1936. This completed the infestation of the entire riverine tract between Calcutta and Shamnagar covering an area of 19 miles. Madhyamgram (11 miles) along the Bongaon section of the E.B. Ry showed some casual infestation in 1936.

It seems curious, however, that in spite of the widespread distribution of the species from Budge-Budge to Falta and from Calcutta to Shamnagar

[1] Breeding detected in 1936.

along the left bank of the Hooghly, the tract lying between Budge-Budge and Calcutta was free from any breeding until the current year, when Akra (13 miles) nearly half-way between Budge-Budge and the Garden Reach area and within a short distance of the Calcutta shipping range was involved in the breeding

From previous records it is evident that the species was breeding in Chengail area (17 miles from Howrah) in 1930 (Iyengar, 1931) Since then evidence of the distribution of the species more generally has been recorded The first finding by the newly constituted survey party on this bank was at Uluberia, nearly 20 miles away from Calcutta on the B N.Ry and about 3 miles west of the old, i.e. 1931, focus of Chengail This detection was made following the capture under interesting circumstances of adult *A sundaicus* in a Uluberia train at Howrah, thus providing another example of the transportation of the species by train The following year 1932 was very favourable for the dispersal of the species in the area. By 1933 the Chengail focus had extended both east and west to Bauria (15 miles) and Fuleswar (19 miles), followed by an epidemic of malaria in the latter place (the spleen rate rising to above 15 per cent) which was formerly a healthy area, and infective stages of the mosquito were recorded. These findings were of great concern to the B.N Ry organization, since the health of the whole Bauria-Uluberia section of the railway was in danger, and the railway had therefore to take up active control measures for this area. The previously existing Government control work at Chengail, which was originally taken up to safeguard the interest of the jute mill owners, merged into that of the railway control measures.

In 1933 an important detection was made of the widespread distribution of the species at Belur in close proximity to the E I Ry. colony at Lillooah and within four miles from Calcutta. This finding resulted in the formulation of the first anti-*ludlowii* scheme at Lillooah (4 miles), a station of great importance under the E I.Ry The upper limit of this species along this bank was also established in the same year by the detection of the species breeding in Mankundu (19 miles) and of adults only in Telenipara under the Bhadreswar Municipality, being almost opposite Shamnagar on the other bank. Thus, from the beginning the species was breeding in areas widely apart, and it was not until the next year 1934 that the Belur focus spread further inwards to Uttarpara (6 miles), a distance of 2 miles from Belur Further progress was made in 1936 when the species was established in Konnagar about 9 miles from Calcutta. An addition was made to the list by the finding of the species in Baidyabati about 15 miles from the city during the current year. Thus, practically the entire tract between Calcutta to Mankundu and as far as the border line of Chandernagore is within the range of *sundaicus* invasion.

Along the B.N.Ry. tract further dispersal occurred in 1935 when adults were recorded from Andul, about 8 miles away, and Sankrail (10 miles), which is almost opposite Akra on the left bank of the river. Both in Sankrail and Akra (E.B.Ry.) the species has been breeding during the current year.

As regards the nature of dispersal of the species northwards towards the city from Port Canning (28 miles), which appeared to be within the *sundaicus* zone, it began as early as 1909. From the very year of commencement of the special survey work in 1931, the species was recorded not only from Port Canning and several villages near it, but from as far northwards as Piali village, about 21 miles away, and the villages Bansra and Manasapukur under the Protapnagar Police Station on the Bidyadhari River. The species spread to Champahati (20 miles), a mile to the north of Piali station, in the year 1932, and was generally distributed along the courses of the rivers Piali and Bidyadhari Taldi (23 miles) and Lakshmipur, between Port Canning and Piali, were also heavily involved in the breeding. Thus by 1933 it was discovered that the portion of the country between Port Canning and Champahati was breeding the species profusely and the endemicity was high in the area, being above 50 per cent in some places. Ghutiari Sharif and the neighbouring villages along this section became involved in 1935

Another important focus, also detected in 1931, was that of Hashnabad, 44 miles away from Calcutta, where the species was breeding in six villages including the influential town of Taki (42 miles). An additional focus along the B.B.Ry. line cropped up in the year 1932 when the species was recorded from Basirhat and Toparchar, about 36 miles away, in large numbers, and by 1934 these merged into one huge tract of *sundaicus*-infected area by the species starting to breed in the intervening stations between Taki and Basirhat. The distribution of the species in the various *bheels* round about Haroa Khal station, about 11 miles away along the same line but leaving a considerable gap from Basirhat, was detected for the first time in 1934. Infected specimens have been known to be transported to Shambazar (Calcutta) through the B.B.Ry. trains from time to time.

The same year, i.e. 1934, gave a more thorough picture of the distribution of the species along the various tidal rivers and *khals* on the north-east of Port Canning and also along the bank of the Ichhamati River past Hashnabad as far as Swarupnagar. The vast undeveloped water-logged area bounded by the river Bidyadhari and the Gobra Khal, involving the three important police stations,—Port Canning, Bhangore and Sandeskhali—was all a *sundaicus*-infested zone. Several villages on the bank of Ichhamati, including Baduria and Swarupnagar, were also involved by 1934.

Active dispersal of the species was revealed as a result of our survey in 1935 in the tract lying between Baruipur, 16 miles from Calcutta, and Diamond Harbour (37 miles south of Calcutta) on the one hand and Joynagar (31 miles to the south) on the other. The invasion of *sundaicus* in these areas resulted in an outbreak of malaria at Baruipur and Joynagar in the autumn of 1935, the spleen rate reaching above 40·0 per cent. *Sundaicus* invasion along the line was more intense in the following year, when the species was recovered from a village (Noapara) near Sonarpur (11 miles) and the entire tract from Garia (8 miles) to Dhakuria (4 miles), the last-named place being

within one mile of Ballygunge, was involved Adult *A sundaicus*, evidently emanating from the Dhakuria focus, was actually reported by Senior-White from Ballygunge, a suburb of Calcutta, during the last year.

SALT LAKE AREA.

The history of the establishment of the species in the Salt Lake area to the east of the city is much more interesting. An eye was always kept over this area from the commencement of the survey work in 1931 Nothing, however, beyond the capture of adult *A. sundaicus* at Kristopur on the eastern border of the lake, from a boat which evidently passed through the *sundaicus*-infested zones on her way to the city, thus providing an example of a good means of dispersal of the species by the country-boat, was recorded in that year It was only towards the end of 1932 that any active breeding of the species could be detected from the lake area and that too only from the portion bordering Noaputty close to Kristopur on the eastern shore. The authorities grew more anxious to protect the city from an invasion through this route, but before any active measures could be taken the species made headway towards the western border of the lake adjoining the eastern fringe areas of Calcutta, and the entire mass of the brackish water collections from Chingrighata to Noaputty, a stretch of about 12 miles, was under *sundaicus* occupation by the end of 1933. Once established in the lake, the onslaught of the species was easier, and in the same year the species actually started breeding in Nebugola under ward 28 of the Calcutta Corporation. The apprehension of *sundaicus* malaria in the city was justified, since in July 1933 an epidemic of malaria broke out in that ward, the spleen rate rising to 20 0 per cent, and infected specimens of the species to the extent of nearly 7 0 per cent were recorded from the area. Before the close of the year 1933, Pagladanga in ward 18 was also involved in the breeding of the species More and more infiltration occurred during the succeeding years, and in the years 1934 and 1935 the species also invaded the most interiorly situated villages of the lake as well as parts of ward 29 of the city More wards of the city were involved in 1936 when heavy breeding was recorded from Tangra, a populous part of Calcutta, in addition to Pagladanga in ward 18, where the species was prevailing from 1933 as well as from Dhapa and Topsia on the south-eastern fringe area of Calcutta. The species again justified its reputation by causing an unprecedented epidemic of malaria in this newly invaded locality of Calcutta in the autumn of 1936, when the spleen rate in some places went as high as 96 per cent. Infectivity in the species was recorded of about 3 per cent during November of the same year. The current year saw the spread of the species in Ghughudanga and Satpukur under ward 31, and we are apprehending an outbreak in the near future in this locality also. This brings to a close the position up to date of *sundaicus* distribution in and around Calcutta, but the survey is by no means

complete and the breeding of the species is being detected from most unexpected spots as time passes.

In conclusion, it may be mentioned that the species is migrating more towards human habitations year after year. This migration has been helped in many places through the agency of transport either by train, country-boat, or perhaps by bus as has been sufficiently indicated from the catches made at the different railway stations, such as Majherat, Sealdah, Shambazar and Howrah, from time to time, as also from the lock-gates at Baghbazar and Kulti. Once transported near human habitations the species takes to its new environment and its great adaptability to various ranges of salinity, even to fresh water, is an additional advantage to the species for establishing itself in a new area. In recent years the species, although normally a brackish-water breeder, has established itself in many places in what may be considered as fresh-water breeding places. To-day it is breeding freely on the one hand in the highly brackish or salt waters of Diamond Harbour and Port Canning (Matla), the salinity varying from 600 to 1100 parts per 100,000, as also in the practically fresh waters of Mankundu or Shamnagar on the other hand, having a salinity of 5 to 7 parts per 100,000. It has been a common experience of workers in estuarine and deltaic faunas that there is always a transformation acting on the life of animals which brings about a change in their activities from sea to fresh water, and *sundaicus* offers a unique example in support of such observations. The heavy rainfall, large tracts of tidal areas with embanked portions of water, uniform soil condition and high temperature with heavy moisture contents have all been helpful in the distribution of the species. The attack of inland waters by the species in the different years has been through different routes and the species when it first invades an area exhibits a somewhat territorial phenomenon, having a distinctly localized distribution, but as years roll on these areas, as we are gradually realizing, have been practically merging into one another, and truly 'the invasion of fresh water from the sea is a slow, hard fought struggle' (Pearse, 1932).

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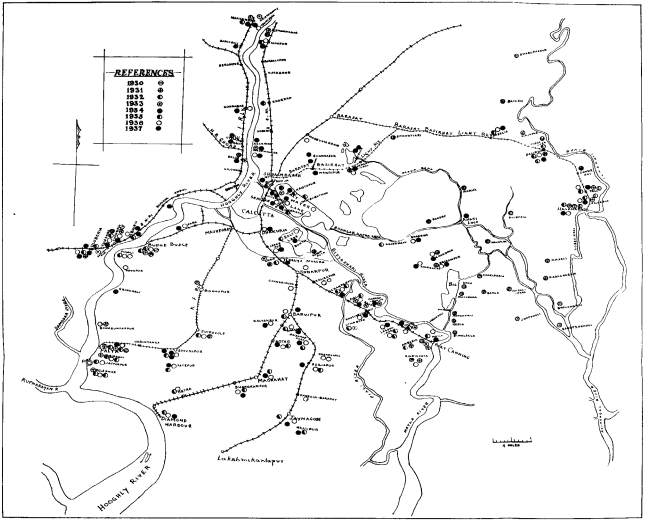
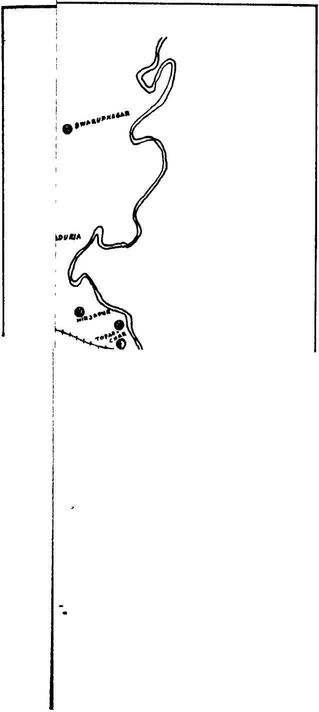


Map showing distribution of *A. sundaicus* in and around Calcutta.


SWARUPNAGAR
DURIA
MIRJAPUR
TOPARA CHAR

NATURAL PARASITES OF MOSQUITOES IN INDIA.

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Several organisms have been recorded as parasites of mosquitoes, but only a few of them appear to be of importance in the economy of nature in the control of mosquitoes One should, however, differentiate between parasites and epiphytes which do not obtain their nutriment from the host, as for example *Characium anophelesi* and *Vorticella* Sometimes certain saprophytes, as for example the fungus *Saprolegnia* observed frequently on dead larvæ, are mistaken for parasites Such fungi are really saprophytic and they come in only after the death of the larva

The parasites recorded fall into the following groups: (1) Bacteria, (2) Fungi, (3) Protozoa, (4) Nematodes, (5) Trematodes, (6) Insects, and (7) Acarines.

Perroncito observed an organism resembling *Leptothrix buccalis* infesting *Anopheles maculipennis*, but no other bacteria have been recorded as causing any morbidity in mosquitoes. Among fungi, the Entomophthoraceæ are known to cause death in adult mosquitoes. Liston (1901) mentioned a filamentous fungus resembling *Trichiphyton* in *Anopheles* larvæ. Laveran (1902) observed a yeast in the body cavity of *Anopheles maculipennis* Vaney and Conte observed *Botrytis bassiana* in larvæ of *Culex pipiens*. Keilin (1921*b*) described *Coelomomyces stegomyiæ* in larvæ of *Stegomyia scutellaris* and Iyengar (1936) described two species of *Coelomomyces* parasitic in *Anopheles* larvæ.

Protozoa: Jaffe (1907) observed a spirochaete (*Spirochaeta culicis*) in the gut of mosquito larvæ in Germany, and Sergent and Sergent (1906) observed a similar organism in larvæ of *Anopheles maculipennis* in Algeria. Their pathological importance is not known ·A gregarine (*Lankesteris culicis*) parasitic in mosquito larvæ was studied by Wenyon (1911). Leger and Dubosq (1902) found a *Diplocystis* infesting mosquito larvæ in Corsica. A schizogregarine (*Caulleryella anopheles*) was observed by Hesse (1918) in larvæ of *Anopheles bifurcatus* in France. Among microsporidia a large number of forms was found to parasitize mosquitoes (Kudo, 1924). The genera concerned are *Thelohania, Nosema, Plistophora* and *Stempellia*. Among ciliates Keilin (1921*a*) found *Lambornella stegomyiæ* in the hæmocele of *Stegomyia scutellaris* in Malaya. Species of *Crithridia* have been observed in the gut of mosquitoes but they do not appear to cause any morbidity in the hosts.

Trematodes: Larval trematodes have been observed in mosquitoes and often cause the death of the host (Sinton, 1917). The further development of these trematodes appears to be in the body of fish (Soparkar, 1917).

Nematodes: Several observations indicate that genera belonging to the family Mermithidæ are frequent parasites of mosquito larvæ and adults (Iyengar, 1929*a*). They cause a fair degree of mortality.

Acarina: Several genera belonging to the family Hydrachnidæ have been observed as ectoparasites of mosquito larvæ and adults. The forms found on mosquitoes are the larval stages of these acarines; their adult stages are aquatic and free-living.

Insecta: Only one insect, *Culicoides anophelis*, has been observed parasitic on mosquitoes. This midge is an ectoparasite of adult mosquitoes and sucks the body fluid of the host, but it does not kill the host It remains fixed to the abdomen of the mosquito by means of its mouth parts. The larvæ are free-living.

In the above list, many of the parasites are of doubtful importance as agents in the control of mosquitoes. Considering the incidence and the morbidity caused in the hosts, the following are of importance in India: (1) *Coelomomyces*, (2) *Microsporidia*, and (3) *Mermithidæ*.

1. *Coelomomyces.*

This genus is probably allied to the *Chytridiales* but its affinities cannot be determined until the sexual phases are known. We have two species in India, *C. indiana* and *C. anophelesica*, both of which infest *Anopheles* larvæ and adults and cause considerable mortality. Several species of *Anopheles* have been observed to be susceptible to this infection. The vegetative forms consist of multinucleated mycelia in the hæmocele of the mosquito and are attached to the fat body by means of minute hyphæ. Sporangia are formed by apical constriction of the mycelium A heavily infested larva is filled with numerous yellowish sporangia. The infection is fatal to *Anopheles* larvæ, and the pathological changes consist of the disappearance of the fat body and the suppression of the development of the imaginal buds. The larva is generally killed before pupation.

2. *Microsporidia.*

Three genera of Microsporidia were recorded by me infesting mosquito larvæ in India, namely, *Thelohania*, *Nosema* and *Plistophora*.

Nosema attacks the epithelial cells of the midgut while the other two genera infest the adipose tissue of mosquito larvæ. These parasites cause considerable mortality in the infected hosts (Iyengar, 1929*b*). In heavily infected larvæ, the further development of the larva is arrested and the larva dies liberating the spores into the water. Their life-histories consist of a schizogonic cycle and a sporogonic cycle. In *Nosema*, the spore mother cell forms a single spore, in *Thelohania* it forms an octospore, while in *Plistophora* it forms more than

16 spores. The spores are minute and dehisce by extrusion of a polar filament, a characteristic of this group The infection happens through swallowing the spores.

3. *Mermithidæ*

These worms live in the hæmocele of the host and cause considerable mortality. The parasitic stages are the larval phases, the adults being free-living and short-lived The life-history of *Mermis* parasitic in *Anopheles* larvæ was described by Iyengar (1929) These worms escape into the water by rupturing the body-wall of the larva After some time in the water, they become sexually mature and give birth to numerous young larvæ which swim about in the water This is the infective stage and they gain entrance into the hæmocele of a new host by piercing through the cuticle of the larva The species infesting mosquitoes in India have not been specifically determined

These three groups constitute, in my opinion, the parasites that play a significant rôle in the natural control of mosquitoes in India Our knowledge of these different parasites is admittedly meagre , further studies are indicated in regard to their distribution, incidence, life-history, and ecology Until further information on these points is available, it is difficult to answer the question which comes to one's mind, ' Can these parasites be utilized for a biological control of mosquitoes ? '

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TRANSMISSION OF *P. INUI* TO MAN.

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(Read at Symposium, August 27-28, 1937)

INTRODUCTION.

Blacklock and Adler (1922) observed malaria parasites in the blood of a chimpanzee in West Africa, some of which resembled *P vivax*, some the band forms of *P. malariæ*, and some the crescentic gametocytes of *P falciparum*. Attempts were made to transmit this infection to man both by blood inoculation and by mosquito-bite (*A costalis*), but neither method proved successful.

Berenberg-Gossler (1909), and Gonder and Rodenwalt (1910) failed to infect man with a similar plasmodium subsequently classified by Sinton and Mulligan (1933) as *P inui* var. *gonderi*. Attempts to transmit *P. brasilianum* to man were made by Clark and Dunn (1931), but it is doubtful whether these were successful. The first undoubted infection in man with a species of monkey plasmodium was obtained by Knowles and Das Gupta (1932) with *P. knowlesi*, when 3 human volunteers were infected with this parasite. In these cases, the incubation period varied from 7 to 20 days and fever lasting about a week was observed in each case. Parasites usually appeared 1 or 2 days before febrile symptoms were observed and they persisted in the blood for some time after the disappearance of fever. Although the body temperature sometime rose above 104°F the number of parasites in the blood was never high In all three cases recovery was spontaneous. These observations were later confirmed by Nicol (1935), by Ciuca *et al.* (1935), and by Van Rooyen and Pile (1935).

MATERIAL AND METHODS EMPLOYED

The strain of *P. inui* used for the present experiment was received in November, 1935 through the courtesy of Lt.-Col J. A. Sinton, I M S., then Director, Malaria Survey of India This strain has since been maintained by passage through a series of four monkeys of which the first three were *S rhesus* and the fourth *S. irus* In order to exclude the possibility of a latent malarial infection in the latter monkey, repeated and exhaustive blood examinations were made and the results were consistently negative. In addition, 2 cc. of blood from this monkey were inoculated into a specimen of *S rhesus* but no malarial infection subsequently developed in the latter animal. There is a strong probability, therefore, that this specimen of *S. irus* was free from natural

malarial infection. When, however, it was inoculated with *P. inui*, parasites appeared in the peripheral blood 9 days after inoculation, and a low grade infection with typical *P. inui* parasites developed.

Since it was found by Knowles and Das Gupta (1932) that a large dose of parasites was required to ensure successful transmission of *P. knowlesi* to man, it was considered desirable in the present experiment to inoculate as many *P inui* parasites as possible The specimen of *S. irus* which was selected as the donor animal for this experiment showed only a scanty infection and it was thought desirable to increase the prevalence of parasites by splenectomising this animal. On the third day after splenectomy about 32 per cent of the red cells were infected and the monkey was obviously ill. It was accordingly anæsthetised and 6 cc. of blood were obtained by cardiac puncture. This was defibrinated and injected intramuscularly into the human volunteer The latter was in good health apart from a scaly skin affection of the forearms and wrists. This individual had been experimentally infected with *Spirillum minus* about eight months previously in order to determine whether there was any acquired tolerance to re-infection in rat-bite fever. With the exception of some febrile attacks induced by the inoculation with *Spirillum minus*, the volunteer gave no history of fever for several years previously.

Results

Twenty-three days after inoculation with *P. inui* from the splenectomised *S. irus* very scanty parasites were detected in the blood of the human volunteer. The number of parasites increased slightly during the seven days that followed and the forms encountered were rings, trophozoites and very scanty schizonts. Gametocytes were not seen at any stage of the infection. On the 28th day after inoculation the patient's temperature began to rise, but febrile symptoms were present only for three days and the maximum temperature observed was 102°F. On the 29th day after inoculation 5 cc of the human volunteer's blood were injected intravenously into a young specimen of *S. rhesus*. A scanty infection with typical forms of *P. inui* developed in the latter animal on the eighth day after inoculation. This infection also remained a low grade one up to the time of writing (22nd day after inoculation) during which period no clinical symptoms had been observed in this animal. Owing to the small number of parasites available for study in this monkey it has not been possible to determine the duration of the schizogony cycle accurately

Discussion.

In the writer's opinion there can be little doubt that the infection produced in the human volunteer was one with a pure strain of *P. inui*. This is borne out by the fact that the infection appeared within a reasonable incubation period, that the morphology of the parasite was typical of a pure infection with *P. inui*, and that when the infection was subsequently passed to a clean

specimen of *S. rhesus* the resultant infection was in every way typical of *P. inui* infection in this species of monkey

There are, however, certain other possibilities which must be excluded These include: (1) the possibility that the human volunteer had a latent malarial infection which flared up as the result of inoculation of monkey blood, (ii) that the volunteer contracted a fresh infection with a species of human plasmodium while in hospital, (iii) that the blood of the donor monkey was infected with both *P inui* and *P knowlesi* and that the infection which developed in the human volunteer was one with *P knowlesi* which, as has previously been shown, is transmissible to man.

(i) It appears to the writer that the possibility of a latent infection in the human volunteer is extremely unlikely This individual gave no history of previous malarial attacks, his blood was repeatedly negative before the monkey blood was inoculated and, if a latent infection had flared up by the injection of fresh blood, it would be expected that this would have made its appearance early in the 23-day period which elapsed before parasites were detected The infection was morphologically identical with *P inui* and since it was subsequently shown to be infective to *S. rhesus*, the probability is that it was not a human species of plasmodium So far as is known, it is doubtful whether *S rhesus* is susceptible to infection with any of the human species of plasmodium Apart from the observation of Taliaferro and Taliaferro (1934) who produced an infection with *P falciparum* in young howler monkeys, and the unconfirmed observation of Mesnil and Robaud (1920) who attempted to infect apes with human malaria, all other attempts to transmit human malarial infections to simian hosts have failed

(ii) The possibility that the human volunteer contracted a fresh infection while in hospital is extremely unlikely, because malaria transmission in Calcutta at this season of the year is rarely known to occur

(iii) There is no reason to believe that the donor monkey (*S. irus*) was suffering from a mixed infection with *P inui* and *P knowlesi* Against this possibility is the fact that after splenectomy the parasitic infection in the donor animal was sufficiently intense to allow of the detection of *P. knowlesi* on morphological grounds.

In view of the fact that a clean specimen of *S. rhesus* was inoculated with the blood of the human volunteer at the time when the infection in the latter was at its height, and that this animal subsequently developed a malarial infection which both clinically and morphologically was in every respect similar to the usual type of *P. inui* infection in *S rhesus*, there is, in the writer's opinion, little or no doubt that the infection produced in the human volunteer was one with a pure strain of *P. inui*.

The absence of gametocytes throughout the whole course of the infection in the blood of the human volunteer is an interesting observation This may perhaps be explained by the fact that the degree of natural resistance to *P. inui* by the human host is sufficiently high to prevent the formation of

gametocytes. It is well known from epidemiological studies that the number of gametocytes in any given community or individual is in inverse proportion to the degree of immunity present.

SUMMARY.

P. inui, a quartan parasite occurring as a natural infection in *S. irus*, has been successfully transmitted to a human volunteer in whose blood the parasites appeared 23 days after inoculation and in which the infection persisted for one week. The number of parasites observed in the blood of the volunteer was never high and recovery was spontaneous Febrile symptoms were observed for three days only. The parasites encountered were rings, trophozoites, and schizonts. Gametocytes were never encountered.

The writer wishes to express his gratitude to Lt.-Col J. A Sinton, I.M S, for his kindness in supplying the strain of *P inui* used in this experiment

His thanks are also due to Major H. W. Mulligan, I M S., for kindly going through this manuscript and making some valuable suggestions.

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OBSERVATIONS ON THE NUTRITION OF *PANCHAX PANCHAX* (HAMILTON)[1]

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(*Read at Symposium, August 27-28, 1937*)

For evaluating the relative utility of the probable larvivorous fishes of India it is of paramount importance to study the various problems connected with their nutrition under natural conditions. A number of workers have by feeding experiments already successfully demonstrated the probable utility of some of the forms, but so far as we are aware very little field work has hitherto been done on the food of the indigenous small minnows. Sen's (1937) recent article on the food-factors of the so-called mosquito-destroying fishes of Bengal is, however, an exception. Though, as pointed out by one of us (Hora, 1937), Sen's technique is not up-to-date in several respects and his conclusions seem to be somewhat premature, all the same his is a pioneer contribution on the subject and deserves careful scrutiny.

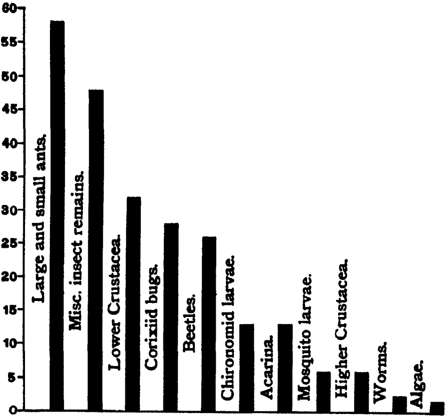
A large number of observers have testified that usually no mosquito larvæ are found in pieces of water where *Panchax panchax* live. This coincidence has been explained on the assumption, strongly supported by laboratory experiments, that *Panchax* feed on mosquito larvæ and are thus very efficacious in the control of mosquitoes. Sen's studies on the natural food of *Panchax*, however, showed that

> 'Even in *Panchax* which is a carnivorous fish only about 10 per cent of the fish examined were found to feed on Anopheles larvæ in their habitat. The diet of *Panchax* is so varied that it seems to have no selective food-habit, and as such cannot be relied upon as a larvicidal fish. Whatever comes along in their way, whether of vegetable or animal origin, if it is not too big for them, is devoured by *Panchax* as in the case of the types of fish studied by Seal. The field observations seem to show that *Panchax* have greater attraction for small moving objects whatever they may be. The employment of fish which are not known to show a definite preference for Anopheline larvæ cannot therefore prove a success in controlling malaria in Lower Bengal.'

From the analysis of the stomach contents of *P. panchax* published by Sen his conclusions would appear to be justified, but he seems to have ignored the fact that no mosquito larvæ have usually been found in the pieces of water inhabited by this fish. We have recently confirmed this observation by surveying a large number of pools, ponds, tanks and drains in the Ballygunge, Tollygunge, Howrah and Pulta Waterworks areas. Though mosquito larvæ were

[1] Published with permission of the Director, Zoological Survey of India.

found in abundance in the puddles at the edges of the collections of water beyond the reach of the fish, the main water areas, which contained fish, were invariably free of mosquito larvæ. The contents of the whole of the alimentary canal of a large number of individuals from various localities were examined and it was found that in the case of only about 6 per cent of the specimens examined mosquito larvæ had been eaten and even then with the exception of one individual the number of larvæ did not exceed 3 in any one specimen, this is certainly



TEXT-FIG. 1 —Graphic representation of percentages of *Panchax panchax* alimentary canals containing different kinds of organisms

Lower Crustacea were mostly Ostracods and higher Crustacea comprised small crabs and shrimps. Under miscellaneous insects are included all undeterminable remains of Arthropods

a negligible quantity in a voracious fish like *Panchax* The food of the fish was found to consist mainly of a variety of insects, such as ants, Corixiid bugs, water beetles and their larvæ, Chironomid larvæ, etc., small Crustaceans, such as Ostracods, Copepods, young crabs and shrimps, water mites, worms, etc. Small quantities of algæ were found in the stomach contents of two specimens collected from a large tank by the side of the Golf Club, Tollygunge.

Some variations were found in the nature of the food of specimens collected at different times of the day and also of those collected from different localities, but sufficient data are not yet available for discussing these points

So far our results are more or less in agreement with those of Sen, but the question naturally arises, had there been mosquito larvæ in the habitats of *Panchax* would they have shown any preference for them? We have attempted to answer this question in two ways, firstly by introducing this fish in pits in which mosquito larvæ were breeding and observing their food from day to day and secondly by providing the fish with a mixed menu in the laboratory and studying at intervals of 30 minutes the food consumed by the fish

Field Experiments

Two valve chambers at the Pulta Pumping Station, designated **A** and **B** in the following notes, were selected for the purpose of the first experiment Both the chambers had collections of water about 2 feet deep and were overgrown with rank vegetation, both under water and along the *pucca* walls Chamber **A**, which is situated near the old Engine Room, is a circular pit approximately 9½ feet in diameter and is about 7 feet deep Chamber **B** is a rectangular pit approximately 12 feet by 9½ feet and about 10 feet deep, it is situated near the new Engine Room Before starting the experiment mosquito larvæ were found in fair quantities in both the chambers—in chamber **A** there were approximately 4 larvæ in a cupped handful of water all over the surface, while in chamber **B** their number was 5 in the same quantity of water [1]

On the evening of the 29th June, 1937, at about 4-30 P M 18 specimens of *P panchax* were introduced in chamber **A** and 19 in chamber **B** By 6 A M next morning the density of mosquito larvæ was reduced to 3 per measure in chamber **A** Three specimens were taken from this chamber and the contents of their alimentary canals were examined From their stomachs 6 mosquito larvæ and 1 Chironomid larva were recovered, whereas from their intestines 17 mosquito larvæ and 2 adult mosquitoes were taken out in a semi-digested condition The three specimens, one female and two males, ranged in total length from 46 to 49 mm

In chamber **B**, at 6-30 A M on the 30th June, 1937, the density of mosquito larvæ population was 4 per measure and the contents of the alimentary canal of 3 specimens dissected were as follows Eight mosquito larvæ in stomachs and 6 mosquito larvæ, 3 adult mosquitoes, 1 fly and 1 beetle, all in a semi-digested condition, in the intestines The specimens ranged in total length from 35 mm to 43 mm and comprised 2 females and 1 male

On the evening of the 30th June no appreciable decrease was noticed in the density of mosquito larvæ in chamber **A**, and 20 more specimens of the

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[1] Not being trained malariologists we regret we did not know at the time any up-to-date method employed in determining the density of mosquito larvæ in a piece of water

fish were introduced, thus bringing the total strength to 35 In chamber B the density of the larvæ decreased to 3 per measure and 35 more fish were introduced in this chamber, thus bringing the strength to 51

On the evening of the 1st July, no mosquito larvæ were found in chamber A, while 2 larvæ per measure were found in certain parts of chamber B. Twenty-five more fish were introduced in the latter chamber. On the next day no larvæ were found in either of the chambers and subsequent observation on the 13th July did not reveal the presence of any mosquito larvæ in them Unfortunately by the time the next observation could be made, water from chamber B had been pumped out and the walls and bottom thoroughly cleaned On the 6th of August, mosquito larvæ were found in this chamber in small quantities and about a dozen fish were introduced No mosquito larvæ were, however, found in chamber A, which had not been disturbed Daily observations taken up to August 15 showed no mosquito larvæ in these chambers The contents of the alimentary canal of fishes taken from these two chambers subsequent to the eradication of the mosquito larvæ were periodically examined and found to contain ants and several other types of insects, but no mosquito larvæ

The above experiment was repeated with two other chambers near the new Engine Room with similar results. In one chamber (about 8 feet in diameter and 6¼ feet deep) the water was very foul smelling and turbid and the bottom was overgrown with long grass The number of mosquito larvæ in it was very great—something like 200–300 in a pint of water taken from the surface About 16 fish eradicated all the larvæ in 4 days, the smell disappeared and the water became clean The fish were later found to be feeding on ants and other types of insects

The examination of the stomach contents of a number of *Panchax* from a pit containing a profuse growth of algæ showed that the fish sometimes ingest small quantities of algæ with their animal diet A number of fish when kept with algæ alone preferred to starve rather than to feed on algal matter It is really amazing how this small fish can manage to devour small crickets, crabs and big black or red ants, which would apparently seem to be too big for the size of the mouth of the fish

The above observations indicate that *P. panchax* shows a definite preference for mosquito larvæ provided they are available Only in their absence or when they are scarce they begin to feed on other types of animal matter, mostly ants. Normally algæ do not form any part of their regular diet.

Laboratory Experiment

For the purpose of a laboratory experiment, water from small pools, in which mosquito larvæ were found, was bailed out into a bucket, thus ensuring the presence of the mosquito larvæ and the associated fauna and flora. A number of specimens of *P panchax* were starved for 4 hours and it was then

found by dissecting six of them that they had practically no food in any part of the alimentary canal. These starved specimens were then introduced into the water collected as above After intervals of 30 minutes, 2 specimens were taken out and the contents of their alimentary canals examined The results of the experiment are tabulated below

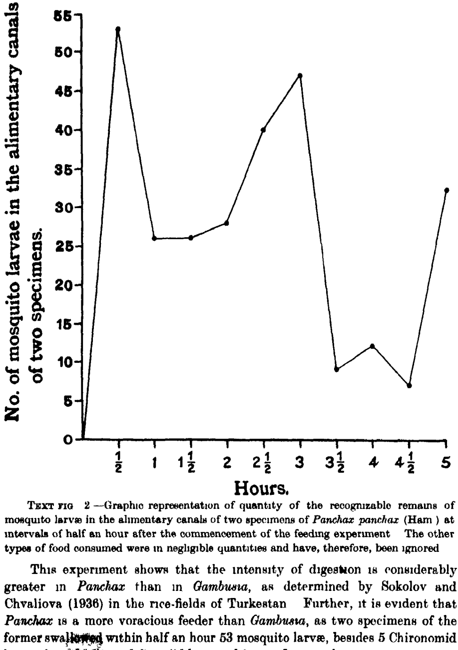
DETERMINABLE CONTENTS OF THE ALIMENTARY CANAL OF *P panchax* (HAM)

Two specimens were examined each time In all 20 specimens were dissected	Mosquito larvæ and pupæ	Chironomid larvæ	Water-mites	Corixid bugs	May fly nymphs
Half hour	53	5	2	2	1
One hour	26	3	7		
One and a half hours	26	2	2	4	
Two hours	28	2			
Two and a half hours	40	1		3	
Three hours	47				
Three and a half hours	9	1		2	
Four hours	12				
Four and a half hours	7	2	1	1	
Five hours	32		2	1	
Total number of animals of each kind in the food of 20 specimens of *P panchax*	280	16	14	13	1

The above results clearly indicate that when a variety of other animal food is available in the habitat of *P panchax* along with mosquito larvæ they prefer to feed on mosquito larvæ. A certain amount of indiscriminate feeding indicated in the above experiment was more marked in the first half of the period of the experiment, presumably because the fish, under the stress of hunger, were more liable to feed on anything that came in their way, but became more selective when their appetite was once satisfied

The above results also show to a certain extent the intensity of digestion in *P panchax* It was observed that in the first half an hour the fish fed voraciously on mosquito larvæ and that their stomachs were probably filled to their maximum capacity. Towards the end of the period the food was just about to leave the stomach, as in one of the two specimens two Chironomid larvæ, one may-fly nymph, two water-mites and three mosquito larvæ had already passed into the intestine. In the next half an hour, however, a fair quantity of the food had passed into the intestine, leaving still an appreciable amount in the stomach. This condition lasted for an hour or so At the close of the second hour feeding was started again and went on for one hour. During this period the food previously taken passed through the alimentary canal where it was seen in the form of a pulp At the commencement of the

fourth hour feeding had slowed down again for an hour and a half after which vigorous feeding was resumed again.



TEXT FIG 2 —Graphic representation of quantity of the recognizable remains of mosquito larvæ in the alimentary canals of two specimens of *Panchax panchax* (Ham) at intervals of half an hour after the commencement of the feeding experiment The other types of food consumed were in negligible quantities and have, therefore, been ignored

This experiment shows that the intensity of digestion is considerably greater in *Panchax* than in *Gambusia*, as determined by Sokolov and Chvaliova (1936) in the rice-fields of Turkestan Further, it is evident that *Panchax* is a more voracious feeder than *Gambusia*, as two specimens of the former swallowed within half an hour 53 mosquito larvæ, besides 5 Chironomid larvæ, 2 water-mites, 2 Corixiid bugs and 1 may-fly nymph.

We fully realize that the experimental data we have presented here are of a very preliminary nature, but the object before us has been to show how for a proper appreciation of the great utility of the indigenous species it is absolutely

necessary not only to carry on extensive field work but also to undertake an intensive study of their ecology and bionomics With regard to *P panchax* we hope to have established beyond doubt that this top-minnow is more efficacious in destroying mosquito larvæ under home conditions than its near cousins of Tropical America belonging to the genera *Gambusia* and *Lebistes*

Panchax are small, surface-feeding fishes, and are exceptionally hardy, as they have been found to tolerate very foul waters and to live in damp situations out of water for considerable periods. It is stated by Chatterjee (1934) that they breed freely throughout the year in confined waters , they are difficult to catch and are not valued as food. Lastly they are out and out carnivorous fishes Thus they satisfy all the requirements laid down by expert malariologists as necessary for a really useful larvicidal form, and we have no doubt that further work on the physiology of its nutrition and breeding habits will reveal several more points in its favour as the most suitable larvivorous species for Indian conditions

Summary

Sen's results regarding the food of *Panchax panchax* under natural conditions are confirmed from a study of the contents of the alimentary canal of a large number of specimens of *P panchax* collected from several localities in the Ballygunge, Tollygunge, Howrah and Pulta Waterworks areas It is, however, pointed out that practically no mosquito larvæ were found in the pieces of water inhabited by the fish From experiments carried out in the field by introducing the fish in mosquito-breeding places, it is concluded that *Panchax* prefer to feed on mosquito larvæ, and only when their supply is exhausted they begin to feed on other animals, mostly insects and especially ants These results are also confirmed by laboratory experiments, in which the fish were given a mixed diet of mosquito larvæ and other types of animals, such as Chironomid larvæ, Corixid bugs, may-fly nymphs, water-mites, beetles, etc. Under these circumstances the fish showed a definite preference for mosquito larvæ It is also observed that, when kept with algæ, the fish preferred to starve rather than to feed on vegetable matter The voracity of feeding and the intensity of digestion of the fish are also studied.

It is thus definitely shown that *Panchax* is a very effective larvicidal fish and its use, under Indian conditions, is strongly recommended

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NOTES ON VREDENBURGITE (WITH DEVADITE) AND ON SITAPARITE

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(*Received March 18, 1938*)

CONTENTS

I. INTRODUCTION

Many years ago I published accounts of two new manganese-ore minerals under the names of vredenburgite and sitaparite respectively.[1] Vredenburgite

[1] 'Three new Manganese-bearing minerals .—Vredenburgite, Sitaparite and Juddite', *Rec. Geol. Surv. Ind.*, XXXVII, pp. 199-212, (1908)

'The Manganese-Ore Deposits of India', *Mem. Geol. Surv. Ind*, XXXVII, pp 42-49 (vredenburgite) and 49-52 (sitaparite), (1909).

 [Published July 4th, 1938.

was obtained from Beldongri in the Nagpur district, Central Provinces, and from Garividi in the Vizagapatam district, Madras, and for this mineral substance, of several possible formulæ, $3Mn_3O_4 \cdot 2Fe_2O_3$ was preferred. Sitaparite was obtained only from one locality, namely Sitapar in the Chhindwara district, Central Provinces, and for this mineral the somewhat complex formula $9Mn_2O_3 . 4Fe_2O_3 . MnO_2 . 3CaO$ was adopted. The specific gravity of vredenburgite was determined as 4·74 (Beldongri) to 4·84 (Garividi) and that of sitaparite as 4·93 to 5·09. The hardnesses were determined as about 6·5 for vredenburgite and about 7 for sitaparite. In colour vredenburgite is dark steel-grey with a bronze tint, especially in the sun, whilst sitaparite is a dark bronze-grey, the bronze tint again being especially well seen in the sun. In each case it was the bronze tint that first drew my attention to the mineral. The streak of vredenburgite is a deep brownish black tending to a deep chocolate, whilst that of sitaparite is black. Each mineral shows a well-marked cleavage [1]; but as no crystals of either mineral were found the directions of these cleavages were not definitely determined. It was suggested, however, that the cleavage of vredenburgite is parallel either to the isometric octahedron or the tetragonal pyramid, according as the mineral is isometric or tetragonal, and for sitaparite that the cleavage may be octahedral. Although these two mineral substances have somewhat similar bronze colours they are easily distinguished by the fact that vredenburgite is strongly magnetic, whilst sitaparite is only weakly so.

Although it seemed clear, in view of these properties, that we had to deal with two new mineral species, it was also clear that there was scope for further work on the chemical composition of both substances, as also for the discovery of crystals of each and the determination of their crystal constants. The opacity of these, as of other manganese-ore minerals, was, of course, a hindrance to the study of their composition and of the relationship of one mineral to another in complex ores; and that the method of the future for the study of manganese-ores was that already adopted for the study of alloys was suggested by my publication in the memoir cited above of a photomicrograph (Plate 1) by reflected light of a polished and etched slice of manganese-ore (a mixture of braunite and psilomelane).

The study of opaque minerals in polished and etched slices by reflected light has since become a well-known branch of technique for the student of ore deposits, and much work has been done on Indian manganese-ores by several workers, in particular by Christie, Schneiderhöhn, and Ramdohr, Orcel and Pavlovitch, and lately by Dr. J. A. Dunn, amplifying, as one result of this work, our knowledge of vredenburgite and sitaparite. This work shows that vredenburgite in its present form is not a mineral species but a mixture of at least two minerals, whilst sitaparite is a definite species. In addition further

[1] As vredenburgite is now known to consist of a lamellar intergrowth the apparent cleavage may be better described as a parting plane.

chemical work has been done on vredenburgite not only in connection with Dr. Dunn's research, but also by Mr. M R Anantanarayana Iyer of Bangalore Further, whilst vredenburgite has not yet been found outside India, except perhaps for the specimen from Jakobsberg in Sweden noticed on page 274, sitaparite has been found to occur abundantly in the manganese-ore deposits of Postmasburg in South Africa

In view of these facts it seems suitable that I should contribute a note upon the additional knowledge acquired concerning these two mineral substances ; and, as the author of the term, perhaps express an opinion on the use of the name vredenburgite in the future now that it has been shown that in its present form vredenburgite is a mixture of minerals.

II. Vredenburgite (with devadite).

(a) *Researches mainly on polished surfaces*

Christie, Schneiderhöhn, and Ramdohr.

In 1928, whilst on study-leave, Dr. W A K. Christie, then Chemist to the Geological Survey of India, polished and etched with H_2O_2 and H_2SO_4 a specimen of vredenburgite from Kodur , the surface thus prepared recalled at once the Widmanstätten figures revealed on polishing and etching a section of a nickel-iron meteorite, this work thus showing that the specimen of vredenburgite examined must now be composite. It appeared in fact to be composed mainly of two substances, one forming the network and the other occupying the meshes of the net. Dr. Christie attempted to drill out and analyse separately under the microscope the two main constituents , but this proved impracticable However, he succeeded in separating these two constituents by dissolving one of them in a mixture of H_2O_2 and H_2SO_4 . but Dr. Christie was not satisfied with the analytical data thus obtained. This work was commenced in Professor Lacroix' laboratory at the Muséum d'Histoire Naturelle in Paris, where the first polished section of vredenburgite was prepared, and then continued first in Professor Hans Schneiderhöhn's laboratory at Freiburg in Breisgau, and later in the Geological Survey laboratory in Calcutta.

To me Dr. Christie's discovery was of extreme interest. For, on the analogy of the interpretation given by me to the crystalline structures of iron meteorites or siderites as revealed by the Widmanstätten figures [1] obtained on polishing and etching, in accordance with which I regarded the formation of these structures in meteorites as indicative of the release of pressure, it appeared that Dr. Christie's discovery provided evidence by analogy that the original vredenburgite had on release of pressure (or lowering of temperature), or both, broken down into two separate minerals, supporting my view that the Eastern Ghats Province of India was a special tract that had formerly been

[1] 'Preliminary Note on the Origin of Meteorites', *Jour. & Proc. As. Soc. Beng.* (New Series), VIII, pp. 320, 321, (1912).

subjected to much higher pressures and temperatures than normal, accounting for its very unusual petrographical and mineral facies.

Dr. Christie's visit to Paris and Freiburg appears to have stimulated research on manganese minerals, including vredenburgite and sitaparite, at both centres, namely in Paris by J. Orcel and St. Pavlovitch and at Freiburg i. Br. by Schneiderhöhn and P. Ramdohr.

The results of the studies at Freiburg have been incorporated in Volume II of Schneiderhöhn and Ramdohr's 'Lehrbuch der Erzmikroskopie' published in Berlin in 1931, and in two papers, one by Orcel alone [1] and the other by Orcel and Pavlovitch,[2] published in Paris in 1930 and 1931 respectively.

The data given in Schneiderhöhn and Ramdohr's volume [3] were based on work by Christie and Schneiderhöhn on the microscopic aspects of vredenburgite This study was made on a specimen from Kodur in the Vizagapatam district, Madras, a locality near Garividi, from which my type specimen from this area was derived. According to these authors (Schneiderhöhn and Ramdohr) vredenburgite in its present form consists of a lamellar network of hausmannite with the meshes occupied by jacobsite, the lamellæ of hausmannite being arranged parallel to the octahedron (111) of jacobsite They write that the structure indicates that an originally homogeneous spinel mineral has broken down because the corresponding admixture was no longer stable with falling temperature. Further, as both components correspond to the formula R_3O_4 (Mn_3O_4 and $MnFe_2O_4$), the composition of the original vredenburgite can be easily determined by planimetric measurement. They remark further that the result so obtained agrees approximately with my formula for vredenburgite if one considers that I gave no valencies for the Mn and Fe.[4] These authors remark that the strongly magnetic character of vredenburgite is due to the magnetism of the jacobsite. It is also noticed that with incipient weathering the hausmannite is often selectively altered before the jacobsite. An excellent photomicrograph brings out the resemblance to the Widmanstätten figures of an iron meteorite already noticed.

Orcel and Pavlovitch.

Orcel and Pavlovitch also give an account of a study [5] of vredenburgite in polished surface, making use of reflecting power, and of chemical attack by a variety of reagents. Their work was done on a specimen from Kodur provided by Dr. Christie. They, also, recognise two constituents, referring to them as α for the constituent occupying the meshes of the network and β for the needles of the network itself. The constituent α is weakly but clearly anisotropic, whilst β

[1] *Bull. de la Soc. Franç. de Min.*, LIII, p. 347, (1930).

[2] *Op cit.*, LIV, pp. 108–179, (1931).

[3] *Loc. cit.*, pp. 602–604.

[4] The distribution adopted by me of the Mn and Fe into sesquioxides and protoxides is based on the determination of available oxygen, which does not, of course, enable one to determine the distribution of Mn and Fe into sesquioxides and protoxides, but does enable one to decide on the proportion of R_3O_4 to R_2O_3.

[5] *Loc. cit.*, pp. 166–170.

is markedly polychroic Judging from their optical characters and reactions to corrosive attack by various agents, the authors decide that neither of these constituents can be identified certainly with already known species Constituent α is very similar in both optical and chemical properties to braunite, but as chemical treatment yielded a residue of only 1 02 per cent of SiO_2 the authors rightly rule out braunite.

They notice also that constituent α might be identified with jacobsite (as is done by Schneiderhöhn and Ramdohr), but for the fact that jacobsite is rigorously isotropic, and that before one could admit this identity it would be necessary to regard the anisotropy as provoked by internal tensions sufficiently regular to give rise to uniform extinctions throughout, which evidently appears to the authors improbable In addition they find the reaction of α to hydrochloric acid different from that of jacobsite.

They consider the possibility of constituent β being hematite (*oligiste*), but reject this on both optical and chemical grounds, and conclude that vredenburgite may be an association of two new constituents, but that no definite conclusion can be drawn without a study by X-ray technique applied to material picked out under the microscope

In addition to α and β they noticed, frequently bordering the needles of β, a fine band of a substance with the characters of polianite

Concerning the relationship of the two constituents α and β to each other, the authors consider that the data suggest that constituent β separated in constituent α after the crystallisation of the latter; and that if this be the case it might be possible, at a certain temperature, to obtain a homogeneous compound. An experiment to test this possibility produced at points a partial fusion of the mineral; and after polishing it was found that at such points the 'needles' had disappeared completely, with replacement by an aggregate of anisotropic crystals with the optical properties of constituent α

Whatever the nature of these two constituents it is clear that this experiment supports the suggestion of Schneiderhöhn and Ramdohr that vredenburgite is a composite substance resulting from the break up of an originally homogeneous mineral on fall of temperature.

In an appendix to their paper (*loc. cit.*, p 177) Orcel and Pavlovitch mention that Volume I of the German authors' work had appeared during the printing of their own paper, and that the authors thereof had identified the two constituents of vredenburgite as jacobsite and hausmannite They mention that they had not dared to identify constituent α as jacobsite for the reasons already given, principally its anisotropy They agree that constituent β exhibits the majority of the characters of hausmannite, but it differs in not being attacked by a saturated solution of $SnCl_2$, whilst hausmannite is so attacked They suggest that this difference might be explained by the presence of foreign materials in the network of hausmannite, modifying its behaviour somewhat to attacking reagents They reiterate the desirability of resolving the doubtful points by an X-ray study

J. A. Dunn.

The next study to be noticed is that of Dr. J. A. Dunn[1] making use mainly of reflecting powers and etching tests. Whilst the authors noticed above had confined their research to material from Kodur in the Vizagapatam district, Dunn examines both my type material from Garividi in Vizagapatam and Beldongri in the Nagpur district, and also various specimens from Kodur and Beldongri, that, judging from their numbers, appear not to be a part of my original collection, but to be derived from the Geological Survey duplicate collection, and not necessarily examined by myself.

Concerning the Vizagapatam material Dunn notes that in the vredenburgite of Kodur, determined by Christie[2] and Schneiderhöhn as a mixture of jacobsite and hausmannite, the hausmannite is usually partly altered to psilomelane and pyrolusite, an alteration also noticed by Schneiderhöhn, although he does not name the alteration products. Dunn notes, however, that a polished piece of my type specimen from Garividi contains only a small proportion of such alteration products. Like Schneiderhöhn he finds the Vizagapatam jacobsite to be isotropic, not noticing the anisotropism detected by Orcel and Pavlovitch.

Dunn then examines the Beldongri material. My type specimen, which agrees so closely in chemical composition with the Garividi material, he finds to be a complex mixture of jacobsite, hausmannite, braunite, pyrolusite, and psilomelane, with some quartz. According to him the jacobsite and hausmannite in this specimen do not always show the intergrowth so typical of the Vizagapatam vredenburgite. One of his published photomicrographs (*loc. cit.*, Plate VI, fig 6), however, shows the typical intergrowth, but also irregular patches of pyrolusite-psilomelane aggregates with what appears to be a reaction rim of braunite separating these aggregates from the vredenburgite, suggesting perhaps that the braunite has been formed from the vredenburgite mixture as an intermediate stage in the alteration into psilomelane and pyrolusite. The other figure in this Plate shows separate patches of hausmannite in jacobsite, the latter containing fine lamellæ, presumably of hausmannite; and the hausmannite patches, which Dunn regards as replacing, show twinning, retaining the direction of the original hausmannite lamellæ in jacobsite.

Combining the information given by Dunn's descriptions and photographs of the polished surfaces of my type material from Garividi and Beldongri, with the fact that on analysis these two specimens gave such very similar results[3] for the principal constituents MnO_2, MnO, and Fe_2O_3, it seems logical to deduce that these mixtures have been formed by the break-down on change of physical conditions of a pre-existing homogeneous mineral and that the

[1] 'A study of some microscopical aspects of Indian manganese-ores', *Trans. Nat. Inst. Sci. Ind.*, I, pp. 103–124, (1936).

[2] Dr. Christie in private conversation informs me that he does not accept responsibility for this determination.

[3] *Mem. Geol. Surv. Ind.*, XXXVII, p. 44, (1909).

composition of this mineral can be deduced from a study of these analyses The Beldongri mineral has, judging from Dunn's account, evidently suffered a greater degree of surface alteration of the secondary metamorphic complex than the Garividi mineral, and this deduction agrees with the higher amount of combined water in the Beldongri specimen , whilst the presence of braunite in the Beldongri mineral, as detected by Dunn, is supported by the presence of 0·91 per cent of combined silica as against only 0 20 per cent in the Garividi specimen. It seems evident that we shall be able to secure a better idea of our primary mineral from a study of the Garividi analysis than from the Beldongri analysis

Whereas the specimen for Beldongri selected by me as the type for analysis agrees so closely chemically with the Garividi mineral and contains a considerable proportion of the characteristic intergrowths of hausmannite and jacobsite, Dunn finds from a study of their polished surfaces that other specimens from Beldongri are much more nearly jacobsite, and he selects two of them for analysis No. 779 (*a*) is estimated microscopically to contain a little more than 2 per cent of hematite and less than 0·5 per cent of psilomelane in minute cracks, and this specimen is regarded as the purest Indian jacobsite yet found. The other specimen, 779 (*b*), was less pure, but was subjected to analysis because the types of jacobsite in (*a*) and (*b*) show slight optical differences . (*a*) is of a darker brownish yellow than (*b*), and whilst (*a*) shows a barely perceptible anisotropism, (*b*) is slightly more anisotropic The analyses were made by Mr. P. C. Roy.

That these specimens are not examples of vredenburgite is seen at once by comparing Mr. Roy's analyses (*loc cit* , p. 108) of specimens 779 (*a*) and (*b*) from Beldongri with the type analyses of vredenburgite from Beldongri and Garividi. The percentages of oxides of manganese and iron and of the two metals are compared below :—

	Vredenburgite		Jacobsite			
Locality	Garividi.	Beldongri	Beldongri.	Beldongri	Jakobsberg	Långban.
No of specimen.	A. 346 or 18/502.	1080 or 18/293	779(*a*)	779(*b*)	Dana. 1.	Dana 2
	Per cent.	Per cent	Per cent.	Per cent	Per cent	Per cent
MnO_2	24 94	23 37	4 82	11 35	4 03	6 96
MnO	38·53	38 24	34 61	33 31	20 72	29 93
Fe_2O_3	31·29	28·85	59 31	53 03	68·25	58 39
TOTAL	94 81	90·76	98·74	97 69	93 00	95 28
Mn	45 62	44·62	29 84	32·96	18 60	27 58
Fe	21·90	20 19	41·50	37 125	47 77	40·87
Sp. Gr.	4 84	4·74	4·90	4·82	4·75	
MgO	1·20	0 99	0 12	0 59	6·41	1 68

It will be seen that whereas in vredenburgite the percentage of manganese is about twice the percentage of iron, in jacobsite, as exemplified by the mineral from the original locality, namely Jakobsberg in Sweden, the reverse relation holds, whilst in both the purer Beldongri specimens 779 (*a*) and (*b*) the iron is substantially in excess of the manganese

According to Dana magnesia is an important constituent of jacobsite ranging from 6·41 to 0·72 per cent in the analyses quoted.[1] In the Beldongri analyses Nos. 779 (*a*) and (*b*) the amounts of MgO are only 0·12 and 0·59 per cent respectively, and this might be thought to militate against this mineral being regarded as jacobsite. As, however, Dunn finds that the mineral agrees optically with jacobsite, it seems simpler to regard the MgO of jacobsite as a non-essential constituent replacing a portion of the MnO.

It is evident, therefore, from Dr Dunn's studies, that some of the specimens from Beldongri registered in the collections of the Geological Survey of India as vredenburgite are jacobsite, and are chemically different from my type specimen from that locality

As, according to Dana, jacobsite is a deep black mineral but magnetic, and hausmannite is brownish black and, presumably, not markedly magnetic, for this property is not mentioned, it appears that vredenburgite owes its magnetic character to the jacobsite and its bronze tint to the hausmannite. It should therefore be possible to distinguish vredenburgite from jacobsite by colour and from hausmannite by its magnetic property The streak is not such a useful property, being blackish brown for jacobsite, deep brownish black tending to deep chocolate for vredenburgite, and chestnut-brown for hausmannite

As there seems to be little doubt that specimen No. 779 is largely jacobsite, it is of interest to see if the analysis of 779 (*a*) supports this Assuming 2 per cent of hematite (estimated from the polished surface) and that the combined water is present as H_4MnO_5, Dr. Dunn calculates three possible formulæ according to three different assumptions :—

(1) $3Mn_3O_4 . 4Fe_3O_4$ or $(Mn, Fe)_3O_4$ in which Mn : Fe = 3 . 4

(2) $Mn_3O_4 . 2Fe_2O_3$.

(3) MnO $(Fe, Mn)_2O_3$. [Actually 1·07 MnO . $(Fe, Mn)_2O_3$]

Formula (2) is clearly inadmissible, as the oxygen error involved is far too large, as Dr. Dunn recognises , whilst formulæ (1) and (3) are equivalent, for

$$3Mn_3O_4 . 4Fe_3O_4 = 7MnO + 7(Mn, Fe)_2O_3,$$
$$= 7[MnO . (Mn, Fe)_2O_3],$$

the ratio of Mn · Fe in the sesquioxide portion being 1 : 6. The small quantity of MgO present could be included in the RO portion without upsetting the formula.

[1] 'System of Mineralogy', 6th Edit, p. 227, (1904).

Dana gives the formulæ of jacobsite and hausmannite as follows :—

Jacobsite	$(Mn, Mg)O \ (Fe, Mn)_2O_3$
Hausmannite . .	$MnO . Mn_2O_3$.

There is thus no doubt that the Beldongri specimen No. 779 (*a*) analysed by P. C. Roy is jacobsite.

Dunn notes what he regards as the replacement of jacobsite by hausmannite (*loc. cit.*, p. 118). As hausmannite is relatively free from iron this should mean the liberation of iron oxide, which, however, is not described. He suggests that the slight anisotropism of the jacobsite is due to pressure and that the 'inversion' of jacobsite to hausmannite is also possibly a result of metamorphism under increased pressure.

(b) Chemical researches

M. R. Anantanarayana Iyer.

Vredenburgite has also been the subject of investigation by Mr. M. R. Anantanarayana Iyer of Bangalore. In a paper with the title 'An alternative formula for Vredenburgite',[1] read in abstract before the Geology Section of the Indian Science Congress at Bangalore in 1932, Mr. Iyer expressed the view that the formula

$$a(Fe_2O_3 . Mn_2O_3) \ b(Fe_3O_4 \ Mn_3O_4)$$

represented the composition of one specimen of the mineral, and that a more general form

$$a(Fe_2O_3 . Mn_2O_3) \ b\{(Fe, Mn)O \ (Fe, Mn)_2O_3\}$$

represented the composition of four specimens including the two described on page 44 of my memoir on manganese, by which Mr. Iyer appears to mean four specimens analysed by him *plus* those of my two specimens. In the discussion on this paper at Bangalore I informed the author that recent work by Dr. Christie had shown that vredenburgite is a mixture of two or more minerals. This caused Mr. Iyer to make a further chemical examination of his four specimens, and the results of this work are given in a paper 'The Formula proposed for the mineral Vredenburgite', presented to the Geology Section of the Indian Science Congress held at Indore in 1936, and published in the *Records, Mysore Geol. Dept.*, XXXIV, pp. 75–84, (1936).[2] The object of this second investigation was to determine by chemical tests whether vredenburgite consisted of two minerals, as Dr. Christie had determined, or of only one, as proposed in Mr. Iyer's formula of 1932.

The material examined was supplied by the Geological Survey of India, and, besides specimens from Devada (No. 690) and Kodur (Nos. 691 and 692) in the Vizagapatam district, included No. 779 from Beldongri, also investigated by Dr. Dunn. The four analyses, with the two of No. 779 given in Dr. Dunn's paper, are shown below, as regards oxides of manganese and iron, the only constituents (with available oxygen) determined by Mr. Iyer :—

1 *Proc. 19th Indian Sci. Cong.*, Bangalore, p. 373, (1932).

2 For abstract, see *Proc. 23rd Ind. Sci. Cong.*, Indore, p. 247, (1936).

Analyst.	Roy.	Roy.	Iyer.	Iyer.	Iyer.	Iyer.
Locality.	Beldongri.	Beldongri	Beldongri	Devada.	Kodur.	Kodur.
No. of specimen	779 (*a*).	779 (*b*)	779	690.	691.	692.
MnO_2 ..	4 82	11 35	15·11	25·73	26 26	52 86
MnO	34 61	33 31	33 11	30 84	32 06	12 76
Fe_2O_3	59 31	53 03	49 78	39 15	38·15	22·93
TOTAL .	98 74	97 69	98 00	95·72	96 50	88 55
Mn	29 84	32·96	35 19	40 15	41 45	43 28
Fe	41·50	37 12	34 82	27 40	26 68	16 03
Molecular ratio $\frac{Mn}{Fe}$ ..	0·73	0 90	1·03	1·49	1 58	2 74
Molecular ratio $\frac{MnO_2}{Fe+Mn}$ ..	0 043	0 103	0·137	0·242	0 245	0 566

The molecular ratios Mn : Fe and MnO_2 : Fe + Mn shown above are utilised by Mr. Iyer in his paper, and to help the reader to understand their significance I give below these ratios for the various mineral substances under discussions :—

	Mol. $\frac{Mn}{Fe}$	Mol $\frac{MnO_2}{Fe+Mn}$
Jacobsite, if $MnO \cdot Fe_2O_3$ . .	0 50	0
Jacobsite, if $3MnO \cdot Mn_2O_3 \cdot 2Fe_2O_3$	1 25	0 11
Vredenburgite, if $MnO \cdot Fe_2O_3 + Mn_3O_4$.	2	0 167
Vredenburgite, if $a(Fe_2O_3 \cdot Mn_2O_3) \cdot b(Mn_3O_4 \; Fe_3O_4)$	1	0 2 (if $a = b$)
Vredenburgite, if $3Mn_3O_4 \; 2Fe_2O_3$	2·25	0 231
Bixbyite, $Fe_2O_3.Mn_2O_3$	1	0 392
Hausmannite, $MnO \; Mn_2O_3$.	..	0 33
My Beldongri specimen	2 25	0 232
My Garividi specimen .. .	2·12	0 235

The method of investigation adopted by Mr Iyer is to treat each specimen with sodium oxalate and dilute sulphuric acid, twice in the cold and once in a water bath, using different times for the various experiments, and making three experiments on each specimen except his No. 4 (692 above), on which, on account of its greater solubility, only two tests were made. His analytical results show that in each specimen, except his No. 1 (779), there is a selective solution of manganese and of MnO_2 leaving residues with lower Mn/Fe and MnO_2/Fe+Mn ratios than in the original specimen, that is residues with higher iron contents. The author deduces from his data that there is free MnO_2 in all the specimens and consequently that the specimens are not homogeneous

chemically. In fact, he considers that his experimental evidence shows that each of his specimens contains free MnO_2—ranging from about 2 per cent in No. 1 to about 40 per cent in No. 4—as an impurity present with the characteristic mineral of each specimen, which he considers is represented by the composition of the residue in each case This latter is a mineral composed of oxides of manganese and iron, exhibiting strong magnetism This is the mineral vredenburgite according to Mr. Iyer The proportions of free MnO_2 and of 'vredenburgite' in each specimen is, on this basis, calculated by Mr. Iyer to be as follows —

	Free MnO_2	'Vredenburgite'	Total
	Per cent	Per cent	Per cent
No. 1	2 13	96 40	98 53
No 2	4 0	91 90	95 90
No 3	16 40	80 33	96 73
No 4	39 60	48 91	88 51

The difference between the total and 100 represents minor constituents that were not determined.

The ratios Mn/Fe and MnO_2/Fe+Mn in these four residues, regarded as the real vredenburgite, vary between wide limits as is shown by the following figures :—

	$\frac{Mn}{Fe}$	$\frac{MnO_2}{Fe + Mn}$
No 1	0 98	0 114
No. 2	1 41	0 187
No. 3	1 18	0 123
No. 4	1·16	0 246

For specimen No. 1 (779 from Beldongri), which is the lowest in free MnO_2, and therefore the purest, according to Mr. Iyer's methods, the author deduces the formula to be

$$a(Fe_2O_3 . Mn_2O_3) . b(Mn_3O_4 . Fe_3O_4)$$

with a Mn/Fe ratio of 1, the ratio $a \cdot b$ being such as to give available manganese peroxide as 13·47 per cent [1] He also deduces that the two groups of the formula are chemically combined and not a mixture of bixbyite and a spinel.

The 'vredenburgite' of the other specimens, in which the Mn/Fe ratio exceeds unity, can also be made to conform to the above formula by adapting it as follows :—

$$a\{(Mn, Fe)O . MnO_2)\} \cdot b(Mn_3O_4 . Fe_3O_4),$$

with the ratios $a : b$ depending on the actual composition.

[1] On Mr Iyer's data (*l.c*, p 78) a=22·48 and b=77 52, or roughly 2 and 7.

Finally, Mr. Iyer suggests that the earlier type formula given above may be taken as the type formula for 'the mineral vredenburgite'.

(c) *Discussion of results.*

Discussion of Iyer's analyses.

This general formula does not, however, cover my original vredenburgite with its empirical formula of $3Mn_3O_4 \cdot 2Fe_2O_3$. This is not surprising, however, for my formula represents the specimen as a whole, and not a residue after partial solution.

In fact, if one compares the Mn/Fe and MnO_2/Fe+Mn ratios of Mr Iyer's residual substances from his specimens Nos. 1 to 4 as shown in the tables in his paper with the corresponding ratios for my vredenburgite, shown with the ratios for jacobsite and hausmannite in the table on page 262 it is clear that the residues for which Mr. Iyer has devised his formula cannot be regarded as vredenburgite. The molecular ratio Mn/Fe determined on my Garividi and Beldongri type specimens is 2·12 and 2·25, whilst in Mr. Iyer's four residues the value of this ratio ranges from 0·98 to 1·41, and in his formula the value of this ratio is 1.

The molecular ratio MnO_2/Fe+Mn as determined on my two specimens is 0 235 and 0·232, and for the formula adopted by me is 0·231; whilst the value of this ratio in Mr. Iyer's four residues ranges from 0·114 to 0·246, the last value being on his most impure specimen Excluding the last value they range from 0·114 to 0·187. The question then arises—if these residues are not vredenburgite, then what are they? The answer appears to be that they are largely jacobsite. This mineral, if free from Mn_2O_3, and corresponding to the formula $MnO \cdot Fe_2O_3$, would show the following molecular ratios —

Mn/Fe	0·50
MnO_2/Fe+Mn . .	0

In practice, however, Mn_2O_3 is always present and for the four analyses of jacobsite given on page 259 the ratios are as follows —

	$MnO \cdot Fe_2O_3$	$MnO \cdot (Fe, Mn)_2O_3$			
		Beldongri 779 (b)	Beldongri 779 (b)	Jakobsberg Dana 1	Långban Dana 2
Mn/Fe	0 50	0·73	0 90	0·40	0·69
MnO_2/Fe+Mn	0	0 043	0 103	0 039	0 065

The most homogeneous of Mr. Iyer's specimens was that represented by analysis No 1 of 779 from Beldongri, and this specimen as a whole before treatment, and in residue after treatment, gave the following ratios :—

	As a whole	Residue
Mn/Fe	1 03	0 98
$MnO_2/Fe+Mn$	0 137	0 114

and is evidently very similar to Dr Dunn's 779 (*b*), which he has shown to be impure jacobsite

Of Mr. Iyer's other three specimens, the fourth, No 692 from Kodur, may be omitted from the discussion, as it is admitted to be very impure

In contrast with specimen No 1 the remaining specimens, Nos 2 and 3 from Devada and Kodur respectively, on treatment by Mr Iyer yielded Mn/Fe and $MnO_2/Fe+Mn$ ratios for residue and solutions that differ considerably from the corresponding ratios for the original specimens, as is illustrated by the following data for No 3, showing the changes with successive stages of solution —

	Period of treatment	Mn	Fe	MnO_2	Mn/Fe	$MnO_2/Fe+Mn$
Complete specimen	Before treatment	41 45	26 68	26 26	1 58	0 245
Residue	5¼ hrs at ordy temp	23 78	20 54	9 98	1 18	0 143
Do	20 hrs at ordy temp	18 04	15 46	7 02	1 18	0 133
Do	40 mins on water-bath	7 35	6 31	2 64	1 18	0·123
Complete specimen	Before treatment	41 45	26 68	26 26	1 58	0 245
Solution	5¼ hrs. at ordy temp	17 48	6 20	16 48	2 87	0 442
Do.	20 hrs. at ordy. temp	24 14	11 12	18 80	2 21	0 339
Do	40 mins. on water-bath	34 63	20 26	23 40	1 74	0 271

These figures indicate that the original specimen of No 3 was a mixture of two principal constituents, and that nearly the whole of the more soluble constituent was dissolved relatively quickly leaving a residue with an Mn/Fe ratio of 1·18, and that thereafter, as further portions of the residue were dissolved, the Mn/Fe ratio of the solution was reduced owing to the dilution of material with a Mn/Fe ration of 2·87 by material with a Mn/Fe ratio of 1·18 The explanation of the fall in the $MnO_2/Fe+Mn$ ratio of the solution is of course similar.[1]

[1] The variations in the value of this ratio in the residues may lie within the limits of experimental error, as the Mn/Fe ratio is constant. Judging from the corresponding figures for specimen No. 2, however, where the sequence of the $MnO_2/Fe+Mn$ ratio is 0 200, 0·185, 0·187 and that of the Mn/Fe ratio is 1 35, 1 35, 1 41, the more probable interpretation

Mr. Iyer recognises that his specimens are composite, but regards them as mixtures of MnO_2, as an impurity, and 'vredenburgite'. But it is clear that the solutions contain portions of both substances and also that the residues are not vredenburgite, if my original material is to remain the type. And it also seems clear that the figures after the greatest amount of dissolution give the nearest approach to the composition of the residue, whilst those after the least amount of dissolution give the nearest approach to the composition of the more soluble constituents. For specimens 1, 2, and 3 these values are as follows :—

Number of specimen.	..	Mn.	Fe	MnO_2.	Mn/Fe	MnO_2/Fe +Mn.	Probable mineral.
1 (779)—Beldongri	Residue Solution	11·67 17·21	12·11 16·08	4·27 8·34	0·98 1·09	0·114 0·159	Jacobsite Do.
2 (690)—Devada	Residue Solution	18·69 9·37	7·68 4·92	5·39 9·26	1·41 1·94	0·187 0·412	Jacobsite. Hausmannite + MnO_2.
3 (691)—Kodur ..	Residue Solution	7·35 17·48	6·31 6·20	2·64 16·48	1·18 2·87	0·123 0·442	Jacobsite. Hausmannite + MnO_2.

The Mn/Fe ratios of the residues in the above table are all possible figures for jacobsite containing a considerable or large amount of Mn_2O_3 replacing Fe_2O_3 (with some surplus MnO_2) ; whilst in Nos. 2 and 3 the values of the MnO_2/Fe+Mn ratio are possible figures for mixtures of hausmannite with some pyrolusite (see table on page 262) plus some dissolved jacobsite (to account for the iron).

The change of these ratios in the residues and solutions in comparison with those of the original specimens is consistent with the more ready solution of substances higher in manganese than the original substance (*e g.* hausmannite and pyrolusite), and with the slower solution of a substance lower in manganese and higher in iron (*e g.* jacobsite)[1] It does not appear, therefore, that Mr. Iyer's analytical results conflict with the view, based on microscopic study, that vredenburgite in its present condition is a mixture of minerals rather than a homogeneous substance.

Recognising, however, that the residues, even after the most prolonged dissolution, still contain an excess of MnO_2 compared with the quantity

is that a small but decreasing proportion of the more soluble, more highly peroxidised, substance remains with the residue until a late stage.

[1] I do not know if the relative rates of solution of pyrolusite, hausmannite, and jacobsite in various solvents have been determined, but Mr. Iyer's work seems to show that with the solvent used jacobsite dissolves the slowest.

appropriate to the jacobsite formula $MnO.(Fe, Mn)_2O_3$ it is desirable to see what is the extent of this departure. The formulæ of jacobsite and hausmannite, accepted as $MnO.(Fe, Mn)_2O_3$ and $MnO\ Mn_2O_3$ respectively, are of course of the same type and can be generalised as R_3O_4. The extent to which Mr. Iyer's specimens depart either in original or after treatment from this general formula can be judged from the following data, in which the empirical formulæ are arranged to show the surplus of RO_2 over R_3O_4 :—

	ORIGINAL SPECIMEN.		AFTER TREATMENT			
	Composition in terms of R_3O_4 & R_2O_3	Composition in terms of R_3O_4 & RO_2	Duration of treatment	Residue	Duration of treatment	Solution.
No. 1 (779)—Beldongri	$3R_3O_4\ 2R_2O_3$	$4R_3O_4\ RO_2$	48 hrs at ord temp	$5R_3O_4 . RO_2$	24 hrs at ord temp	$15R_3O_4\ 5RO_2$
No 2 (690)—Devada	$R_3O_4\ 3R_2O_3$	$5R_3O_4 . 3RO_2$	40 mins on water-bath	$3R_3O_4\ RO_2$	3½ hrs at ord temp	$5R_3O_4\ 2RO_2$
No 3 (691)—Kodur.	$5R_3O_4 . 13R_2O_3$	$23R_3O_4 . 13RO_2$	do	$11R_3O_4\ RO_2$	5½ hrs at ord. temp	$3R_3O_4 . 5RO_2$
Garividi type	$8R_3O_4\ 7R_2O_3$	$23R_3O_4\ 7RO_2$				
Beldongri type.	$3R_3O_4\ 2R_2O_3$	$4R_3O_4\ RO_2$				

These data show that the original specimen, in each case, contains the RO_2 group in excess of the R_3O_4 formula. This may be due to the alteration (or replacement) of hausmannite to psilomelane and pyrolusite as detected by Dunn in both the Beldongri and Kodur specimens studied by Iyer (Dunn did not examine the Devada material). As shown above, Mr. Iyer's experiments show a selective solution of the RO_2 group and a reduction of this in the residue, which could on this interpretation be entirely jacobsite, or jacobsite with some hausmannite.

Discussion of my type analyses.

Now that we have good reason for regarding vredenburgite in its present form as an association of jacobsite and hausmannite with a certain proportion of other minerals in much smaller proportions, such as psilomelane, pyrolusite, braunite, and, in the material from Beldongri, hematite, it seems desirable to reinvestigate the mineralogical composition of the type-specimens as represented by the analyses given on page 44 of my Memoir already referred to. In each case we will assume that the magnesia is in the jacobsite, that the combined silica is due to the presence of braunite, and that the alumina, baryta, surplus lime (after allowing for apatite and calcite), alkalies, and combined water are present in psilomelane, and also, based on Dunn's work, that there is 2 per cent of hematite in the Beldongri mineral. On these assumptions the mineral composition of the two specimens is :—

	Beldongri 1080 or 18/293. Per cent.	Garividi. A. 346 or 18/502. Per cent
'Vredenburgite'	75 33	89 13
Braunite	9·12	2 00
Psilomelane .	10 16	8 60
Hematite . .	2 00	
Quartz	0 86	.
Apatite	2 48	0 07
Calcite .	0 20	
TiO_2 .		0 14
S ..		0 03
As_2O_5 . .	0 01	
Moisture . .	0 18	0 20
	100 34	100 17

I have placed inverted commas about the first item because it has still to be determined whether the term vredenburgite should be applied to the whole of each of these specimens or restricted to the hausmannite-jacobsite intergrowths. If the above mineralogical interpretations are sound, then the composition of the 'vredenburgite' should be susceptible of interpretation in terms of $Mn_3O_4+MnO . Fe_2O_3$, without knowledge of what proportion of the Mn_3O_4 is hausmannite and what proportion is in the jacobsite. The composition of the 'vredenburgite' in the two analyses corresponds fairly closely to the following :—

Beldongri .. . $3MnO . 2Mn_3O_4 . 3(MnO . Fe_2O_3)$.
Garividi . . .. $3MnO . 12Mn_3O_4 . 13(MnO . Fe_2O_3)$

In each case there is a notable surplus of MnO, amounting to 12·97 per cent (on the total analysis) and 3·69 per cent respectively.

A recalculation of the mineral composition on the assumption that psilomelane is absent, and that the Al_2O_3, BaO, and other oxides are present as impurities, shows then a surplus of 5·17 per cent of MnO_2 in the Beldongri specimen, and of 8·27 per cent in the Garividi specimen. Treating this surplus as pyrolusite, the mineral compositions can then be shown as follows :—

	Beldongri 1080 or 18/293 Per cent.	Garividi A. 346 or 18/502 Per cent.
'Vredenburgite'	76 37	85 89
Braunite . .	9 12	2 00
Pyrolusite ..	5 17	8 27
Hematite	2 00	....
Quartz ..	0 86	. .
Apatite .. .	2 48	0 07
Calcite .. .	0 20	..
Impurities .	3 96	3 74
Moisture . .	0·18	0 20
	100·34	100·17

The composition of the 'vredenburgite', as thus separated from the other constituents of the specimen, is then as follows —

	Beldongri	Garividi
	Per cent	Per cent
(Mn, Mg)O . Fe_2O_3 ..	38 01	44 28
MnO Mn_2O_3 . ..	38 36	41·46
	76 37	85·89

It is, of course, impossible from these data to determine what proportion of the MnO Mn_2O_3 is associated with the (Mn, Mg)O Mn_2O_3 as jacobsite, and what proportion is in the form of the mineral hausmannite If half the MnO Mn_2O_3 were in the jacobsite then the ratio of jacobsite to hausmannite in the 'vredenburgite' would be roughly 3 1, any other proportion could of course be selected to suit actual proportions as determined by measurement on a polished surface under the microscope

It will be seen that the second interpretation of these analyses gives a more satisfactory composition for the 'vredenburgite', in that there is no surplus MnO over the R_3O_4 formula On the other hand, psilomelane has been shown to be present in these minerals under the microscope This does not really cause any difficulty, for

$$2MnO_2 = MnO_3 + MnO,$$

so that it would be simple to represent this MnO_2 as psilomelane by utilising sufficient of the 'impurities' in accordance with the general formula R_2MnO_5 adopted for psilomelane in my Memoir on the manganese-ore deposits of India On the other hand, if the view be adopted that psilomelane is merely a colloidal mixture of oxides of manganese and other substances, there is again no difficulty in regarding a portion or all of the MnO_2, with the 'impurities', as forming psilomelane Consequently, in the second interpretation the pyrolusite and 'impurities' may be regarded as representing such mixture of psilomelane and pyrolusite as the facts require

Comparison of Iyer's analyses with my types.

As my pair of type specimens from Beldongri and Garividi respectively yield on the foregoing interpretation such closely concordant analyses and compositions for the 'vredenburgite' portions thereof, it is of interest to submit to similar treatment Mr Iyer's pair of analyses of specimens Nos 2 and 3 from the two closely adjoining mines of Devada and Kodur in the Vizagapatam district

As Mr. Iyer's analyses are only partial, it is not known if any allowance should be made for the presence of braunite, as would be revealed by the presence of combined silica; but, assuming that all the undetermined constituents can be regarded as 'impurities', mainly available, with surplus MnO_2, to enter into the composition of psilomelane, we can show the mineral composition of the Devada and Kodur specimens as follows :—

	Devada. No. 2 or 690 Per cent.		Kodur. No. 3 or 691. Per cent.	
'Vredenburgite':—				
$MnO.Fe_2O_3$	56·55	78·24	55·10	79 52
$MnO.Mn_2O_3$	21·69		24·42	
Pyrolusite or surplus MnO_2 ..	17·48		16·98	
'Impurities'	4·28		3·50	
	100 00		100 00	

It will be seen that although the Devada-Kodur pair of specimens, on this interpretation, are as similar mineralogically to each other as are the Beldongri-Garividi pair, yet there are marked differences between the two pairs. The differences and similarities are brought out in the following table :—

	$3Mn_3O_4.2Fe_2O_3$.	Beldongri.	Garividi.	Devada specimen	Kodur specimen.	Devada residue.	Kodur residue
R_3O_4 ..	91 36	74 47	85 89	78 24	79 52	89·87	96 88
Surplus MnO_2	8 64	5 17	8 27	17 48	16 98	10·13	3 12
	100·00	81 54	85·89	95 72	95 50	100 00(*a*)	100 00(*b*)
A. R_3O_4/surplus MnO_2 .	10 57	14 77	10 39	4 47	4 68	8 86	31·06
B. Molecular — $\frac{MnO\ Fe_2O_3}{MnO\ .\ Mn_2O_3}$	1·00	0 998	1 064	2 61	2·25	2·16	2·43
C. Mn/Fe in R_3O_4	2 00	1 997	1 893	1·08	1 17	1·20	1·125
D. MnO_2/Fe+Mn in R_3O_4 .	0 167	0 167	0 176	0 093	0 103	0 106	0 098

(*a*) 25 75 per cent of the original specimen. (*b*) 18 96 of the original specimen.

The figures for the residues from the treatment of the Devada and Kodur specimens are also given, from which it is seen that the only important result of the treatment is the reduction in the proportion of MnO_2 surplus to the R_3O_4 formula Whether we consider either the original specimens of the Devada-Kodur pair or the residues from their treatment, we see that in all the three molecular ratios given in the above table this pair is persistently different from the Beldongri-Kodur pair. In the Devada-Kodur pair the $MnO.Fe_2O_3/MnO\ Mn_2O_3$ ratio is over double, the Mn/Fe ratio is nearly half, and the MnO_2/Fe+Mn ratio is about two-thirds of the corresponding ratios for the Beldongri-Garividi pair.[1]

[1] These differences are not due to the fact that in the Beldongri-Garividi pair a certain proportion of the oxides of manganese and iron have been excluded and treated as present in braunite and hematite. If no allowance is made for braunite and hematite, ratios A, B, C, D above become 1 022, 1·007, 1·990, and 0·166, respectively for the Beldongri specimen; and 8 62, 1·127, 1·831, and 0·156 respectively for the Garividi specimen.

That this difference should exist is surprising, for Garividi is close to Kodur and Devada[1] in the Vizagapatam District, whilst Beldongri is some 300 miles away in the Central Provinces

Devada and Kodur specimens not vredenburgite, but show a similar intergrowth.

When the Devada and Kodur specimens were originally named vredenburgite they had not been analysed, now that they have been analysed it is clear that they can no longer be regarded as examples of this mineral substance, if chemical analysis is to be taken as the criterion. It so happens, however, that one of these two specimens, namely that from Kodur, has also been examined microscopically by Dr. Dunn, and found to contain a hausmannite-jacobsite intergrowth similar to that characterising the Garividi specimen,[2] so that if the name is to be applied to hausmannite-jacobsite intergrowths irrespective of the proportion in which these two minerals are present in the intergrowth, and of the proportion of MnO Fe_2O_3 to MnO Mn_2O_3 in the jacobsite, then chemical composition has to give precedence to structure

Whether chemical composition or structure is to be the deciding factor in the nomenclature really depends upon the significance of this intergrowth of hausmannite and jacobsite It is agreed by all who have worked on vredenburgite that this intergrowth must represent the result of the break-down of a once homogeneous mineral, due probably to a change in the physical environment of the primary mineral, for example a fall of temperature, with or without a concurrent fall of pressure, presumably at a time when the mineral and its associated rocks were deeply buried and subject to physical conditions much more severe than those experienced at the surface.

Primary vredenburgite.

If we can assume that when this break-down of the primary homogeneous mineral took place conditions were such that no removal or addition of constituents occurred, particularly of oxygen, then, allowing for the possibilities of subsequent modifications at or near the surface, such as hydration and oxidation, with formation of such a mineral as psilomelane, we ought to be able to deduce from the present composition of the purest material available the composition of the primary vredenburgite

Of the two specimens originally investigated by me that from Garividi was undoubtedly the purer, consisting as it did of large crystal units with a noticeable cleavage (or parting) and marked polarity The greater purity is also indicated by the analyses. Assuming that in both specimens the iron was present as Fe_2O_3 and the manganese as Mn_3O_4, and assuming trivial errors in the determination of available oxygen, it was found that both the Beldongri and the Garividi analyses corresponded closely to the formula $3Mn_3O_4 \cdot 2Fe_2O_3$.

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[1] See map, *Mem. Geol. Surv. Ind*, XXXVII, p. 1051.

[2] *Loc. cit.*, p. 116.

But if the oxygen, manganese, and iron as actually determined be utilised, then the formulæ approximate to—

Beldongri[1]	.. ..	$7Mn_2O_3 \cdot 10(Mn, Fe)_3O_4$,
Garividi	.. .. ..	$7Mn_2O_3 \cdot 8(Mn, Fe)_3O_4$,

with Mn : Fe in the $(Mn, Fe)_3O_4$ approximately 1 : 1.[2]

If one assumes that the primary vredenburgite was a compound including not only the constituents of the hausmannite and the jacobsite, but also the surplus MnO_2 now represented by pyrolusite and psilomelane, then some such formula as those just given may represent the primary mineral, with the sesquioxide group nearly as important as the protosesquioxide group.

The break-down of the Garividi formula would then give some such result as the following :—

$$2\ [7Mn_2O_3 \cdot 8(Mn, Fe)_3O_4] = 12\ (MnO \cdot Fe_2O_3) + 11\ (MnO \cdot Mn_2O_3) + 7MnO_2,$$

Products of break-down of primary vredenburgite.

or if the simplest formula for vredenburgite used in my Memoir be adopted, then the break-down can be shown more simply as follows :—

$$3Mn_3O_4 \cdot 2Fe_2O_3 = 2(MnO \cdot Fe_2O_3) + 2(MnO \cdot Mn_2O_3) + MnO_2.$$

The composition of a mineral of formula $3Mn_3O_4 \cdot 2Fe_2O_3$ would be :—

		Per cent.
MnO_2	.. ..	25·92
MnO	.. .. ..	42·30
Fe_2O_3	.. ..	31·78
		100·00

and this rearranged to show the composition after break-down in accordance with the foregoing equation gives :—

		Per cent.
$MnO \cdot Fe_2O_3$	.. .. ..	45·88
$MnO \cdot Mn_2O_3$	.. .. ..	45·48
MnO_2	.. ..	8·64
		100·00

It is unknown what decides the distribution of $MnO \cdot Mn_2O_3$ between hausmannite and jacobsite, but if half goes to each then the composition of the intergrowth formed by the break-down of $3Mn_3O_4 \cdot 2Fe_2O_3$ would be :—

[1] There is an error in the Beldongri calculations on page 48 of *Mem. Geol. Surv. Ind.*, XXXVII. The figures for Mn_2O_3 and Mn_3O_4 should read 27·89 instead of 28·23, and 33·54 instead of 34·64.

[2] 1·218 and 0·957 respectively.

				Per cent
Jacobsite	$MnO\ Fe_2O_3$—45 88			
	$MnO\ Mn_2O_3$—22 74		..	68·62
Hausmannite	..	..	.	22·74
Pyrolusite	..	.	..	8 64
				100 00

The composition of jacobsite of the composition shown above would be —

			Per cent.	Långban Per cent
MnO	. ..	..	30 82	54 80
Mn_2O_3	.	..	22·87	
Fe_2O_3	.		46 31	43 85
MgO			...	0·94
SiO_2 and CaO				1 15
			100 00	100 74

The composition of the second Långban analysis in Dana is placed alongside for comparison.

It seems clear from the evidence of the microscope that vredenburgite in its present form is characteristically and mainly an intergrowth of hausmannite and jacobsite, with the latter mineral predominating. It seems equally clear from the chemical side that both my original vredenburgite and also the material examined by Mr Iyer, together with the residues from their chemical treatment, contain MnO_2 in excess of that required for the hausmannite-jacobsite intergrowths, which should conform to the general formula RO R_2O_3 or R_3O_4 Such surplus MnO_2 is at least in part present in the form of visible psilomelane and pyrolusite, of which the former may be held to be due to later oxidation (Dunn, *e g* describes the replacement of hausmannite by psilomelane) Orcel and Pavlovitch have recorded, however, that in addition to the α and β constituents of vredenburgite there is also frequently a fine band of a substance with the characters of polianite bordering the needles of β (*i e* of hausmannite). There appears to be no evidence that this supposed polianite is later in age than the two principal constituents of the intergrowth , and we seem here to have evidence of the existence of the surplus MnO_2 required by the break-down equation given above. As, however, such surplus MnO_2 is not always observed as an apparently original constituent of the intergrowth, and as the amount of surplus MnO_2 required for a mineral of original composition $3Mn_3O_4\ 2Fe_2O_3$ is only 8·6 per cent, it is also possible that within small but unknown limits such surplus MnO_2 may remain latent in solid solution in the hausmannite-jacobsite intergrowth. This possibility might account for the fact that even after the most severe treatment Mr Iyer's residues still contain a surplus of MnO_2 over the R_3O_4 formula It might also account for

anisotropism in some of the jacobsite. In the Beldongri material there is clear evidence of the presence of other minerals than hausmannite and jacobsite, e.g. pyrolusite-psilomelane aggregates in figure 6 of Dr Dunn's Plate VI.

Primary vredenburgite not a spinellid.

The evidence is admittedly incomplete, but on the whole it seems necessary to adopt the view that the primary vredenburgite, before the assumed break-down with change of conditions, had not the simple R_3O_4 formula, but in addition contained surplus R_2O_3,[1] as is shown by the simplest formula adopted by me for the type material. In fact, on this interpretation, the primary mineral was not a plain spinellid. Had it been so there seems to be no reason why, on change of physical conditions, the primary mineral should have separated into hausmannite and jacobsite, unless the different crystal symmetry at ordinary temperatures, one being tetragonal and the other cubic, should be sufficient cause. It seems necessary in any case to assume that the association of this surplus R_2O_3 with R_3O_4 was only stable at a relatively high temperature (and/or pressure), and that on fall of temperature (and/or pressure), the Mn_2O_3 separated into MnO_2, and Mn_3O_4, with the occasional separation of surplus Fe_2O_3 as hematite (*cf* Dunn's Plate VI, figure 4).

On this basis we may accept the primary vredenburgite of Beldongri and Garividi as a mineral of the formula $3Mn_3O_4 \cdot 2Fe_2O_3$ $(=4R_3O_4 \cdot RO_2)$, which has, on lowering of temperature (and/or pressure), split up into a secondary vredenburgite consisting of a predominant hausmannite-jacobsite intergrowth, with some surplus MnO_2, now represented by visible pyrolusite and psilomelane, or by surplus MnO_2 in solid solution in the intergrowth.

A secondary intergrowth from Jakobsberg.

Attention must be drawn, however, to an analogous substance from Jakobsberg, Sweden,[2] which gave an analysis closely resembling my vredenburgite analyses, but in which the proportions of oxides can be interpreted as agreeing closely with the ratio $RO : R_2O_3$, so that no surplus MnO_2 is present. This Jakobsberg mineral also shows a lamellar intergrowth assumed to be a spinel and hausmannite. The proportions of MnO, MnO_2, Fe_2O_3, Mn, and Fe may be compared with those for my Beldongri and Garividi specimens as below :—

	Beldongri.	Garividi.	Jakobsberg.
MnO_2	23 67	24 94	23·17
MnO ..	38·24	38 53	42 65
Fe_2O_3	28 85	31·29	30 68
	90·76	94·86	96·50
Mn .. .	44 62	45 62	48·20
Fe . ..	20·19	21·90	21 48

The Jakobsberg mineral has a Mn/Fe ratio of 2·24, and a molecular ratio of MnO_2/Fe+Mn of 0·211, both close to those for vredenburgite of formula

[1] $R_3O_4 + RO_2 = 2R_2O_3$.

[2] K. Johanssen, *Zeit. f. Krist.*, Vol. 68, p. 116, (1928).

$3Mn_3O_4 \cdot 2Fe_2O_3$ The second ratio is lower than for my two specimens due to the substantially higher MnO in the Jakobsberg mineral

Devadite. On referring to the table on page 270 it seems, at first, that we cannot admit the Devada and Kodur specimens to be vredenburgite because of the great departure of the molecular ratios B, C, and D, from those of the type vredenburgite of Beldongri and Garividi The reason for these differences is the much higher proportion of $MnO : Fe_2O_3$ in the Devada-Kodur pair than in the type mineral, affecting ratio B, and consequently ratios C and D, which depend on B It is evident that the primary mineral of Devada and Kodur before break-down could not have had a formula even approximating to $3Mn_3O_4 \cdot 2Fe_2O_3$, owing to the much higher percentage of iron ; and that if we were dealing with the pure minerals in a form that we could handle we should require different names for the two forms (the Devada-Kodur pair and the Beldongri-Garividi pair), in the same way as the various members of the spinellid group of minerals have different names to indicate their different compositions, *e g* magnetite, mangan-magnetite, and jacobsite. In fact it seems necessary to propose a name for the mineral represented by the two specimens from Devada and Kodur analysed by Mr. Iyer The name of the village Kodur has already been used for the rock series with which the manganese-ore deposits of this part of India are associated ; it seems suitable therefore to use the name of the other locality and to call this mineral *devadite*

To obtain an approximate idea of the composition of the primary devadite we must assume that the constituents not estimated in Mr. Iyer's analyses Nos 2 and 3 represent impurities, and as the two analyses are so closely similar we may take an average of the two —

	Devada.	Kodur	Mean	Molecular ratios
	Per cent.	Per cent	Per cent	
MnO_2	25·73	26·26	26·00	Mn_3O_4 = ·1442 = 5 × ·0284
MnO	30·84	32·09	31·46	Mn_2O_3 = ·1547 = 5 × ·0309
Fe_2O_3	39·15	38·15	38·65	Fe_2O_3 = ·2416 = 8 × ·0302.

This gives an approximate formula of $5Mn_3O_4 \cdot 5Mn_2O_3 \cdot 8Fe_2O_3$ The break-down of this primary devadite into the secondary intergrowth can be represented as follows :—

$$2[5Mn_3O_4 . 5Mn_2O_3 . 8Fe_2O_3] = 16(MnO . Fe_2O_3)+7(MnO \cdot Mn_2O_3)+13MnO_2$$

This corresponds to the following composition after break-down —

	Per cent.
$MnO . Fe_2O_3$	57·48
$MnO . Mn_2O_3$	24·93
MnO_2	17·59
	100·00

Since we have found it necessary to introduce a separate name for the Devada-Kodur pair of specimens it is desirable to set out side by side the available data for vredenburgite and devadite in order to display the similarities and differences. This is done herewith:—

	Vredenburgite.	Devadite.
Formula (primary mineral)	$3Mn_3O_4 . 2Fe_2O_3$	$5Mn_3O_4 . 5Mn_2O_3 . 8Fe_2O_3$
Formula (secondary aggregate)	$4R_3O_4+MnO_2$	$23R_3O_4+13MnO_2$
Chemical analysis (formula):—	Per cent	Per cent
MnO_2	25 92	27 06
MnO	42 30	33 13
Fe_2O_3	31 78	39 81
	100 00	100 00
Mn	49 16	42 77
Fe	22 24	27 87
Mineral analysis (formula):—		
$MnO . Fe_2O_3$	45 88	57 48
$MnO . Mn_2O_3$	45 48	24 93
MnO_2	8 64	17 59
	100 00	100 00
R_3O_4/MnO_2	10 57	4 68
	Molecular	Molecular
$MnO . Fe_2O_3/MnO . Mn_2O_3$	1 00	2 29
Mn/Fe in primary mineral	2 25	1 56
Mn/Fe in R_3O_4	2 00	1 09
MnO_2/Fe+Mn in primary mineral	0 231	0 244
MnO_2/Fe+Mn in R_3O_4	0 167	0 101

It is evident from a study of these figures that the chief difference between vredenburgite and devadite is the great difference between the ratio of $MnO . Fe_2O_3$ to $MnO . Mn_2O_3$, this being unity for vredenburgite and about $2\frac{1}{4}$ for devadite. It is also evident that future research may lead to the discovery of material with intermediate values for this ratio and that it will then be necessary to decide whether to introduce still another name or preferably to partition the intervening field between vredenburgite and devadite.

The vredenburgite group of mineral substances.

Although chemical facts appear to require two names as proposed, yet without chemical examination it is not on present data possible to distinguish devadite from vredenburgite Consequently it will be necessary to continue to use the term vredenburgite in a general sense as the name of a group of substances, recognising that on closer examination

some of the substances so named will prove to be different from the original vredenburgite, *i e* from vredenburgite in its restricted sense [1] We shall also be able to continue to speak of the vredenburgite type of structure or intergrowth irrespective of the actual proportions of the constituent hausmannite and jacobsite.

Whilst I have given above special *formulæ for the original vredenburgite* and for devadite, a general formula can be devised to cover them both, and also related substances This formula is

$$a\mathrm{Mn_3O_4} \,.\, b(\mathrm{Mn,\ Fe})_2\mathrm{O_3}$$

a formula, which is obviously related to the general formula proposed by Mr Iyer (see page 263).

The formulæ of vredenburgite and devadite have been discussed on the assumption that the MnO_2 (or a portion of it) must be regarded as one of the products of break-down of the primary mineral This is based on the inherent assumption either that the MnO_2 was a part of the primary mineral or that the surplus oxygen was in some way occluded in the primary mineral, and in the latter case participated in the break-down of the primary mineral with production of free MnO_2 Such a case would be analogous to those discussed by me some years ago in connection with the formation in the Central Provinces of deep-seated manganese-oxide ores from manganiferous silicates and of deep-seated calcite from calc-silicate minerals [2] Should, however, later research show that all the surplus MnO_2 in these secondary vredenburgitic aggregates is to be attributed to surface oxidation, without selective attack upon either of the principal minerals of the assemblage, then taking the figures from the table on page 276) and excluding the surplus MnO_2, and taking also the analysis of the substance from Jakobsberg, Sweden, referred to on page 274, we may compare the ratios of MnO Fe_2O_3 and MnO Mn_2O_3 as follows —

		Jakobsberg 'mineral'	Vredenburgite	Devadite
$(Mn, Mg)O$ Fe_2O_3		43 35	45 88	57 18
MnO Mn_2O_3		51 52	45 48	24 93
Ratio $\frac{Fe_2O_3}{Mn_2O_3}$	..	0 85	1 00	2 29

The formula for the primary mineral is then in each case MnO $(Fe, Mn)_2O_3$, the differences lying in the ratio of Fe_2O_3 to Mn_2O_3 The ratio for the Jakobsberg substance is sufficiently close to that for vredenburgite for the primary Jakobsberg mineral to be included under vredenburgite

[1] If these minerals were commoner and the matter, therefore, of more importance it would be easy to remove the ambiguity arising from the use of the term vredenburgite in both an extended and a restricted sense, by retaining the term in the extended sense that it has acquired and proposing a special term for the original mineral, *garividite* would then be appropriate. This refinement seems unnecessary, however, at present.

[2] 'On the Formation in Depth of Oxidized Ores and of Secondary Limestones', *Comptes Rendus*, XII, *Congrès géol. intern. Toronto*, pp. 271–274, (1913).

The essential difference between jacobsite and the vredenburgitic minerals then lies in the low Mn_2O_3 contents of jacobsite

Postscript to Section II

Since this paper was written, I have received from Mr. M R. Anantanarayana Iyer a copy of a later paper entitled ' A Graphical Representation of the Composition of some Manganese minerals including a discussion of the nature of Vredenburgite ', *Rec Mys Geol Dept.*, XXXV, pp 73–85, (1937). Some additional analytical results are given, reinforcing the author's previous work. Taking account of the microscopical demonstration of other authors that vredenburgite contains hausmannite lamellæ, Mr Iyer treats this as an intergrowth not with jacobsite, but with an assumed definite compound vredenburgite, and in his covering letter to me Mr Iyer writes that from the results discussed in the two papers published he finds it difficult to believe that some specimens of vredenburgite do not contain a compound whose molecule contains more oxygen in it than is present in a spinel mineral containing manganese and iron

As seen above I have accepted the surplus MnO_2 as having probably been an inherent part of the presumed primary vredenburgite, and treat the secondary vredenburgite (and devadite) as intergrowths of jacobsite and hausmannite, with the surplus MnO_2 not required by the spinel formula now appearing as pyrolusite or psilomelane, or possibly sometimes concealed in solid solution

Mr Iyer gives an ingenious graph showing the position of various manganese and iron oxide minerals My two vredenburgite analyses fall on the line ON in his group representing the formula $a\mathrm{Fe_2O_3}\ b\mathrm{Mn_3O_4}$, and his two analyses of what I now call devadite fall on the line MP representing the formula $a\mathrm{Fe_3O_4}.b\mathrm{Mn_2O_3}$ Using the general formula $a\mathrm{Mn_3O_4}.b\mathrm{(Mn,Fe)_2O_3}$ for the vredenburgite group adopted by me, it is not surprising to find that the spots representing these four analyses in Mr. Iyer's diagram fall roughly on a straight line with bixbyite, $\mathrm{Fe_2O_3}.\mathrm{Mn_2O_3}$, which might then be regarded as the end member of the vredenburgite series in which a = zero.

III. Sitaparite

Christie, Schneiderhöhn, and Ramdohr.

Sitaparite has also been studied in polished and etched surfaces by Christie and Schneiderhöhn and their results confirmed by Ramdohr, and an account of this research, based in a study both of material from Sitapar, the original Indian locality, and on specimens from Postmasburg in South Africa, is given in the work already cited [1] According to Schneiderhöhn and Ramdohr sitaparite shows close resemblances both to braunite and to jacobsite, being closer to the former Under the ore-microscope sitaparite is distinguished from braunite by its somewhat yellower tint and slightly greater

[1] ' Lehrbuch der Erzmikroskopie ', pp. 572–574, (1931).

brightness, and greater degree of etching with hydrofluoric acid. Both sitaparite and braunite are found to be weakly anisotropic No cleavages are seen The chief difference is the complicated lamellar twinning seen in both Indian and South African sitaparite. From jacobsite, which, like sitaparite, is olive-yellow towards braunite and also magnetic [1], sitaparite is distinguished by anisotropism and somewhat greater hardness Although the crystal system of sitaparite is unknown, it is regarded as probably tetragonal like braunite, and with the same lattice

The authors point out that as the occurrences of sitaparite are in manganese-ore deposits formed by the regional or contact metamorphism of sedimentary manganese-ore deposits the mineral is probably more widely spread than is at present known. It is also suggested that the somewhat complicated formula for sitaparite adopted by me may be interpreted as representing an original psilomelane gel that on metamorphism has crystallised in the braunite lattice This is, of course, only surmise, as it is not known that sitaparite and braunite do possess the same lattice

South African sitaparite.

Professor Schneiderhöhn also discusses sitaparite in a paper on the manganese-ores of Postmasburg in South Africa [2] In these ores, based on his microscope studies, he recognises various stages of past metamorphic history, as shown in the following statement (retaining only the ore minerals) .—

		Manganese and iron minerals
Diaphthoretic and sub-recent to recent weathering products		Psilomelane Pyrolusite Limonite *Polianite II*
Metamorphic paragenesis	Second stage First stage	Sitaparite Braunite-hematite
Pre-metamorphic remains	Archo-metamorphic [3] minerals and diagenesis.	Polianite II Manganite
	Primary minerals	Not received (probably pyrolusite psilomelane, limonite)

[1] I find sitaparite to be much less strongly magnetic than vredenburgite, and therefore presumably than jacobsite to which vredenburgite appears to owe its strongly magnetic property. Also braunite is weakly but distinctly magnetic. See *Mem. Geol. Surv. Ind*, XXXVII, p. 63, (1909)

[2] 'Mineralbestand und Gefüge der Manganerze von Postmasburg, Griqualand West, Südafrika', *Neues Jahrb. f. Mineralogie, etc.*, Beilage-Band 64, Abt. A (Brauns-Festbuch), pp. 701–726, (1931).

[3] F. Rinne's term to describe the commencement of metamorphic alteration and its resultant minerals, *loc. cit.*, p. 704.

From the study of the sitaparite of this locality it is often seen that a large idiomorphically bounded crystal has broken down into a number of irregularly bounded units of varied orientation with lamellar structures recalling the twinning lamellæ of leucite: and the conclusion is drawn that sitaparite represents the product of enantiomorphic alteration of a cubic or tetragonal mineral stable at a higher temperature into a tetragonal or rhombic mineral stable at a lower temperature. Crystals with zonal structure are also found, and the shells are probably not all of the same composition An outer shell of braunite is not uncommon. Inclusions of hematite are also present, often as relict structures cutting through the crystals. On the other hand lamellæ of sitaparite occur in braunite and are regarded not as the result of the breaking down of a pre-existing mineral, but as due to parallel growth The braunite also contains specular hematite zonally arranged The hematite of these ores is regarded as contemporaneous with the braunite

Concerning the relationship of sitaparite to braunite and hematite Schneiderhohn finds that in the Postmasburg ores sitaparite is younger than braunite and grows idioblastically therein, the hematite included in the braunite largely disappearing in the process The author concludes, therefore, that sitaparite represents a higher stage in the metamorphism of braunite, rendered possible at higher temperatures and pressures in the presence of hematite, thus —

Braunite + Hematite → Sitaparite

$$Mn . MnO_3 + Fe_2O_3 \rightarrow (Mn, Fe)MnO_3$$

Orcel and Pavlovitch.

Orcel and Pavlovitch (*loc. cit.*, p 158) have also studied sitaparite, and their results are given in the paper already cited The material used was that of Sitapar only The only difference between the results of their work and that of Schneiderhohn and Ramdohr is that they find sitaparite to be isotropic and therefore to belong to the cubic system, whilst cleavages were detected The anisotropy noticed by Schneiderhohn and Ramdohr may be due to strain, and it may be recalled that the α constituent of vredenburgite was found to be anisotropic by Orcel and Pavlovitch and, as jacobsite, isotropic by Schneiderhöhn and Ramdohr

J. A. Dunn.

Dunn (*loc. cit.*, p. 111) finds the sitaparite of Sitapar to be so weakly anisotropic as to be regarded as isotropic at times He also discusses (*loc cit.*, pp 114, 115) the mutual relationships of the sitaparite-braunite ores of Sitapar He finds that the braunite veins and replaces the sitaparite; in ore from Gowari Warhona in the same district, the braunite may be replacing the sitaparite, but the relation is more akin to that of simultaneous intergrowth. Dunn considers (p 121) that at least a portion of the braunite in these Chhindwara ores is later than the sitaparite (and hollandite), and that the formation of this later braunite must be regarded as due to regressive metamorphism. As the direction of change noticed in the Indian ores is the reverse of that observed by Schneiderhöhn

in the Postmasburg ores, Dunn looked for evidence of the reversal of Schneiderhöhn's equation given above. No hematite was found, but, as Dunn remarks, the Fe_2O_3 might possibly have been absorbed by the hollandite

Perhaps I may contribute to this discussion on the relationship of braunite to sitaparite

Discussion of results.

Two comments may be made on the simplified formula assigned by Schneiderhohn to sitaparite It is true that by neglecting about 13 per cent of its constituents my formula for sitaparite (see page 254) can be simplified to $9Mn_2O_3 \; 4Fe_2O_3$ and the latter rearranged as $(Mn_5Fe_8)(MnO_3)_{13}$ or $(Mn, Fe)MnO_3$ But this involves regarding the whole of the very considerable amount of iron (19 32 per cent in the specimen analysed) as present in the ferrous condition in the presence of peroxidised manganese

The other comment applies to the formula assigned to braunite Many years ago I went very carefully into the composition of braunite and in particular into the point whether silica is an essential constituent [1] One conclusion was that whilst it seems necessary to recognise the possible existence in Nature of a mineral with a composition corresponding to the formula Mn_2O_3, such mineral must be extremely rare (*loc cit*, p 64) A second conclusion was that braunite is probably an isomorphous mixture of manganites of the general formula $RMnO_3$ and of metasilicates of the general formula $RSiO_3$, giving the formula

$$m\mathrm{RMnO_3} + n\mathrm{RSiO_3}$$

Further, as in all the analyses considered the ratio of $m : n$ lies between the limits of 3 1 and 4 1, and as manganese is the predominant basic constituent, the formula may be stated more definitely as

$$m\mathrm{MnMnO_3} + n\mathrm{MnSiO_3}$$

with the ratio $m : n$ usually between the limits of 3 1 and 4 1 (*loc cit*, p 67).

As the original braunite of Elgersburg in Thuringia and of St Marcel in Piedmont each contain high silica (8 63 and 7·70 per cent respectively corresponding to ratios of $m : n = 7 : 2$ and $4 : 1$) it must be emphasised that the correct formula for braunite must be one allowing for the presence of a substantial amount of silica Mn_2O_3 is an exceptional mineral and should its existence be satisfactorily proved it should be given a separate name

Further, in the Memoir cited, an analysis is given of braunite from Sitapar, showing 8 52 per cent of SiO_2, giving $m : n = 15 : 4$ It seems clear then that Schneiderhöhn's equation, if applied to Sitapar minerals, would have to show a liberation of free silica in one direction and an absorption in the other As no analysis appears to have been published it is not known whether the braunite of Postmasburg contains silica or not, and consequently whether Schneiderhohn's equation in its present form applies even there Judging from the analyses

[1] *Mem. Geol. Surv. Ind.*, XXXVII, pp 63-77, (1909).

of the ores as exported, which show percentages of silica comparable with those of Indian ores, it seems likely that the South African braunite is a normal one with substantial amounts of silica

As Dr Dunn has found that some of the Sitapar braunite has been formed by the replacement of sitaparite, it is of interest that both minerals contain notably high amounts of lime . 4·28 per cent in the braunite and 6·14 per cent in the sitaparite.

When in South Africa in 1929 I met Dr. Schneiderhohn at Kimberley during one of the excursions of the International Geological Congress, and he informed me then that he had found sitaparite in the ores of Postmasburg. At the end of the Congress excursions I returned to Kimberley specially to visit Postmasburg, and was able to verify for myself the presence of sitaparite in this field and to collect specimens. At the time it appeared to me that the tint of the sitaparite of Postmasburg was less bronze-like than that of Sitapar, though showing a distinct yellowish cast as compared with the other minerals in the ores This indicated some variation from the composition of the Indian sitaparite ; but as my collection of manganese-ores was unfortunately lost in transit, I was not able to test this point.

As Dr. Schneiderhöhn's micro-photographs appear to justify his conclusion that at Postmasburg braunite and hematite have together yielded sitaparite, and as the liberation of SiO_2 has not been noticed as accompanying this process, we must assume that the liberated silica has been removed in solution from the scene of reaction, or less probably (see above) that the braunite of Postmasburg is one of those rare examples of braunite corresponding to the formula Mn_2O_3 without $MnSiO_3$ in isomorphous admixture.

It appears therefore that careful chemical analysis of both the braunite and the sitaparite of Postmasburg is desirable.

It will be seen from the above that there is doubt about the crystal system of sitaparite. When originally described by me no crystals had been found, but I suggested that the almost perfect cleavage planes might be octahedral (*loc cit*, p. 49) Schneiderhöhn and Ramdohr consider that the mineral was originally either tetragonal or cubic, more probably the former on account of its anisotropism ; whilst Orcel and Pavlovitch regard it as cubic on account of its isotropism. Specimens from Sitapar were later obtained by me showing crystal faces suggesting the octahedron · but these faces were not sharp enough for crystallographic study.

At Postmasburg also I collected specimens showing octahedral crystals in cavities, but these were in the lost collection. So it still remains unknown whether these faces belong to the cubic octahedron or to the tetragonal pyramid.

IV. Summary

(a) *Vredenburgite and devadite*

In this paper an account is given of the micrographic work on vredenburgite done of recent years by Christie, Schneiderhöhn and Ramdohr, Orcel and

Pavlovitch, and Dunn, and the chemical work by Anantanarayana Iyer. By combining these results with those originally obtained by myself, it proves possible to make suggestions concerning the composition and nomenclature of vredenburgite.

2. Vredenburgite in its present form is a composite substance, characterised chiefly by a microscopically visible intergrowth of hausmannite and jacobsite, the latter predominating In addition there is usually, associated with this intergrowth, pyrolusite or psilomelane, or both In any case chemical analysis always reveals the existence of a surplus of MnO_2 over the general formula R_3O_4 of the hausmannite-jacobsite intergrowth, so that when such surplus MnO_2 is not recognisable as a separate mineral it may be assumed to be included, possibly in solid solution, in the visible minerals of the intergrowth

3 It is probable that vredenburgite in its present form is the result of the breakdown, on amelioration of metamorphic conditions (*e g* falling temperature and/or pressure), of an original homogeneous mineral, to which the term *primary vredenburgite* may be applied

4. Assuming that the surplus MnO_2 in the *secondary vredenburgite* of our collections has, at least in part, been liberated on the breakdown of the primary vredenburgite, it seems correct to utilise the results of the chemical analysis of our secondary vredenburgites, after allowing for impurities and surplus minerals to deduce the composition of the primary vredenburgite On this basis slightly differing formulæ result for the type specimens from Beldongri and Garividi, but they are sufficiently close to the simplest formula already proposed in my Memoir on the manganese-ore deposits of India, namely $3Mn_3O_4 . 2Fe_2O_3$, for the latter to be adopted.

5 From this primary vredenburgite the secondary vredenburgite of our specimens is assumed to have been formed according to the following equation :—

$$3Mn_3O_4 . 2Fe_2O_3 = 2(MnO\ Fe_2O_3)+2(MnO\ Mn_2O_3)+MnO_2,$$

the right-hand side of the equation corresponding to the following composition —

	Per cent	
$MnO\ Fe_2O_3$ .. .	45 88	Hausmannite-jacobsite intergrowth
$MnO\ Mn_2O_3$	45 44	
MnO_2	8 64	
	100 00	

6 Taking $MnO . (Fe, Mn)_2O_3$ as the formula of jacobsite and $MnO\ Mn_2O_3$ as that of hausmannite, it is obviously impossible to allocate the $MnO\ Mn_2O_3$ between the jacobsite and the hausmannite, except on the basis of actual measurement of the areas occupied by the two minerals as shown on polished

surfaces. These surfaces show that the jacobsite is always largely predominant over the hausmannite. If we allocate the $MnO . Mn_2O_3$ equally between the two minerals, then we have a ratio of jacobsite to hausmannite of about 3 to 1, and the jacobsite has a composition agreeing roughly with that of one of the Långban analyses Actually, judging from the published figures, the proportion of jacobsite is usually greater than this.

7 If we are correct in treating surplus MnO_2 as a part of the primary vredenburgite, then the latter was not a plain spinellid, and the breakdown, on lowering of the metamorphic conditions, may be due to the rejection of this surplus; and the separation of the remaining R_3O_4 into jacobsite and hausmannite may be due to the existence of a limit to which MnO Fe_2O_3, the fundamental jacobsite, can retain $MnO . Mn_2O_3$ in isomorphous association at lower temperatures and pressures, and to the fact that under ordinary conditions MnO Mn_2O_3 as hausmannite possesses tetragonal symmetry as opposed to the cubic symmetry of jacobsite

8 Should evidence ever be forthcoming to show that the surplus MnO_2 of secondary vredenburgite is all of later origin, so that the primary mineral was a spinellid in composition, then the breakdown on amelioration of conditions can be interpreted as due to the separation of tetragonal hausmannite from cubic jacobsite, due to immiscibility under these lower conditions

9. The purest available specimen of vredenburgite is my type material from Garividi, which shows large crystal units with well-developed 'cleavage' planes, these being presumed to be pseudomorphs after the crystal units of the primary mineral, and not units of the present intergrowth

10. The cause of the magnetic properties of the secondary vredenburgite is, of course, the jacobsite The deep brownish black to deep chocolate streak of vredenburgite is derived from the blackish brown streak of jacobsite and the chestnut-brown streak of hausmannite.

11. Of the specimens investigated chemically by Mr. Iyer, two, from Devada and Kodur respectively, gave analytical results closely concordant with each other, but differing widely in composition from the Beldongri-Garividi type pair. The principal difference lies in the ratio of MnO Fe_2O_3 to $MnO . Mn_2O_3$, which is 2 29 in the Devada-Kodur pair against 1·00 in vredenburgite of composition $3Mn_3O_4 . 2Fe_2O_3$ This difference affects also Mn/Fe ratios and the ratio of MnO_2 to Fe+Mn On the other hand the specimens exhibit the physical properties of vredenburgite, and the one microscopically examined (Kodur) shows the hausmannite-jacobsite intergrowth.

Whilst, therefore, the Devada-Kodur pair must be accepted as belonging to the vredenburgite group, yet a separate name seems necessary to prevent confusion. The name *devadite* is proposed

12. The principal chemical differences between vredenburgite and devadite are shown on page 276. They may be summarised in the following formulæ and ratios :—

	Vredenburgite.	Devadite
Primary mineral Secondary aggregate	$3Mn_3O_4 \; 2Fe_2O_3$ $4R_3O_4 + MnO_2$	$5Mn_3O_4 \; 5Mn_2O_3 \; 8Fe_2O_3$ $23R_3O_4 + 13MnO_2$
Mn/Fe of R_3O_4	2 00	1 09

Roughly speaking vredenburgite is the high-manganese member of the series and devadite the high-iron member. Should intermediate members of the series be subsequently found they should be termed vredenburgite or devadite according to their chemical affinity.

13. As a general formula for the group, we may adopt

$$a\mathrm{Mn_3O_4} \;\; b(\mathrm{Mn, Fe})_2\mathrm{O_3}$$

if we are referring to the primary mineral, or

$$a\mathrm{R_3O_4} + b\mathrm{MnO_2}$$

if referring to the secondary aggregate

14. The structure of both secondary aggregates may be appropriately referred to as the *vredenburgite structure*

15 Should subsequent research show that the MnO_2 of the secondary aggregates is additional and not proper thereto, then the formulæ of primary vredenburgite and devadite both become

$$\mathrm{MnO} \;\; (\mathrm{Fe, Mn})_2\mathrm{O_3},$$

with the ratio of Fe_2O_3 to Mn_2O_3 ranging from unity for primary vredenburgite to 2¼ for primary devadite, the ratios for hausmannite being zero and for jacobsite much higher than for devadite (16·7 per Damour's type specimen)

(*b*) *Sitaparite*

16. An account is also given of the micrographic work by the same authors, upon sitaparite, both from its original locality Sitapar in the Chhindwara district in India, and from the Postmasburg field in South Africa.

17. Schneiderhohn's work shows a passage of braunite plus hematite into sitaparite, and the following is suggested as the type of reaction —

$$\text{Braunite} + \text{Hematite} \rightarrow \text{Sitaparite}$$
$$\mathrm{Mn \;\; MnO_3} + \mathrm{Fe_2O_3} \rightarrow (\mathrm{Mn, Fe})\mathrm{MnO_3}$$

As normal braunite contains from 8 to 10 per cent of SiO_2 as $MnSiO_3$, silica should appear on the right side of the above equation In its absence it must be presumed either that the Postmasburg braunite is of abnormal composition, or that silica has been removed in solution from the scene of action The formula for sitaparite given in the above equation is a simplification of mine and has not been justified by chemical analysis

18 Dunn in studying the Chhindwara sitaparite finds braunite later than sitaparite, and regards the formation of braunite as here due to regressive metamorphism, but he did not find any evidence of the reversal of

Schneiderhöhn's equation. It is evident that the micrographic work on the South African mineral requires amplification by the separation and analysis of both sitaparite and braunite.

19. Under the microscope sitaparite from South Africa shows lamellar structures recalling those of leucite, and Schneiderhöhn concludes that sitaparite represents the product of enantiomorphic alteration of a cubic or tetragonal mineral stable at a higher temperature to a tetragonal or rhombic mineral stable at a lower temperature

20 It is still unknown whether sitaparite is a cubic or tetragonal mineral, though crystals showing apparent octahedral faces have been found.

(c) *General.*

21. Both vredenburgite and sitaparite show under the microscope structural evidence of a change of one form of a mineral into another, thought to be due to a amelioration in metamorphic conditions, that is to say to falling temperature and perhaps falling pressure. There is no evidence, but only analogy, to guide us in choosing between these two factors , both may have played their part.

DISCUSSION ON L. L. FERMOR'S PAPER 'NOTES ON VREDENBURGITE (WITH DEVADITE) AND ON SITAPARITE'.

The author discusses the recent research of several workers on 'vredenburgite' and sitaparite which were found by him some 30 years ago. I have a few comments to offer from my own knowledge of these minerals and of the significance of recent methods of attack

Sir Lewis' discussion makes me regret that I have not had the pleasure of illustrating to him some features of these minerals which are so clear under the reflecting microscope. I feel sure that had he such microscopic acquaintance with these minerals his discussion would have been other than it is and reduced to a few salient points.

It should first be remembe.ed that 'vredenburgite' is *not* a mineral but a mixture or intergrowth of two minerals jacobsite and hausmannite, and should always be written either in italics or in inverted commas. Such regular intergrowths are quite abundant in mineralogy, it is not customary to give them special names, and I, personally, in this particular case, see no real necessity now for the term 'vredenburgite,' much less Sir Lewis' new term 'devadite'. The structure of the intergrowth is exactly comparable to that of magnetite and ilmenite, and other mineral groups, intergrowths which have been known long before that of 'vredenburgite' and to each of which a special name has not been found necessary , hence again, I find no necessity for the term 'vredenburgite structure'.

The typical intergrowth is of jacobsite and hausmannite, but in a large number of specimens there has been definite alteration, due to weathering,

of the hausmannite to pyrolusite and psilomelane, that is, oxygen has been *added* The author leaves it to subsequent research to 'show that the MnO_2 of the secondary aggregates is additional'—I can assure Sir Lewis that in every case I have yet examined there is not the slightest evidence other than that this added oxygen *is* due to later alteration There is no alternative to the reading of the evidence of the pyrolusite and psilomelane If additional MnO_2 could be proved in the *jacobsite* the case would be different, but I maintain, in the absence of chemical analyses done on material which has been examined under the microscope and proved to be free of alteration, that not one of the analyses discussed by Sir Lewis supplies evidence on which a reliable discussion could be based It is not correct to say that analyses of 'vredenburgite' *always* reveal the existence of surplus MnO_2—the so-called 'vredenburgite' which I found to be almost pure jacobsite in my paper, showed no such excess. Hence, the known unaltered jacobsite contains no excess MnO_2 whilst the obviously altered 'vredenburgite' does. The inference is obvious

This does not mean to say I do not believe that excess oxygen might *not* originally have been present In magnetite—related to jacobsite—excess of oxygen in the crystal lattice is well-known and, by analogy, there is the possibility of it being present in some jacobsite This is no reason why separate formulae should be given for mixtures of the type discussed Well-known gradations of magnetite—mangan-magnetite—jacobsite occur according to the proportion of Fe . Mn present, and there are dozens of other similar graded mineral groups, so that it does not appear necessary to find a term 'devadite' merely for an Fe-rich hypothetical 'vredenburgite' which, as a mineral, could only have existed at a high temperature In fact both may be regarded as high temperature Mn-rich jacobsites from which, on cooling, hausmannite separated. In any case there is no need for this additional nomenclature, it is an unusual practice in mineralogy for hypothetical minerals which do not now exist to be named in this way

Most previous workers regarded the intergrowth as due to falling temperature. Sir Lewis would add the possibility of falling pressure—I know of no similar mineral intergrowth from which the analogy of falling pressure could be drawn.

I would like to say a few words about the formulæ of braunite and sitaparite. Microscopic examinations of these minerals show the unlikelihood that the analyses were done on perfectly pure material. The relatively constant SiO_2 content of the few braunite analyses have no more significance, say, than the commonly constant SiO_2 content of a granite; the latter is a mixture so may be the former Until reliable analyses are done on *known* pure minerals I would favour Schneiderhöhn's simplified formulæ for both braunite and sitaparite.

J. A Dunn.

Reply to Discussion.

I must thank Dr Dunn for his contribution to this discussion. I have not, of course, attempted in this paper to produce new evidence, but merely to discuss the work that has been done on vredenburgite and sitaparite by several workers, of whom Dr. Dunn is one

Whilst it is clear that there is secondary psilomelane and pyrolusite in specimens of vredenburgite, the evidence as to the source of the *whole* of the surplus MnO_2, referred to with such certainty by Dr. Dunn in paragraph 4 of his contribution to the discussion, has not appeared to me conclusive, and consequently I have allowed for the possibility of the presence in the primary mineral of MnO_2 surplus to the spinellid formula. [The unaltered jacobsite to which Dr. Dunn refers at the end of the same paragraph is not regarded by me as a form of vredenburgite, on account of its very different Mn/Fe ratio, apart from the absence of hausmannite] I have, however, in paragraph 8 of my summary, provided for the possibility, supported by Dr Dunn, that all the MnO_2 in vredenburgite may be of secondary origin, in which case the primary mineral was a spinellid.

Concerning nomenclature, no one who disapproves of my terms need use them, and instead he can speak of hausmannite-jacobsite intergrowths or mixtures

I did not in this paper intend to embark on a discussion on the formula of braunite The relatively constant amount of silica in braunite from several different localities abroad was thought by Dana to be of sufficient importance to justify representation of this constituent in the formula of the mineral. Subsequent work in India has added strong support to Dana's view, and it seems unlikely that the silica present in braunite is of fortuitous origin. An X-ray study of braunite would be of great interest as showing whether this silica enters into the space lattice or not

L. L Fermor.

THE RÔLE OF NITROGEN COMPOUNDS IN THE FERMENTATION OF FRUIT JUICES

By N N Chopra

(Communicated by Prof J. N Ray, D Sc, Ph D)

(*Received March 21, 1938*)

It is well known that nitrogen compounds are essential for the growth and activity of the yeast cells, *Saccharomyces ellipsoideus* (1, 2) During the fermentation of fruit and berry juices, any deficiency in the nitrogen content has often to be made good by the addition of compounds which contain nitrogen in an easily available form (3, 4, 5). Grape juice rarely needs such artificial additions as it contains sufficient nitrogen compounds for the primary fermentation and the subsequent enzymic changes. Contrary to Nolte (4) the present author finds that the fresh juice of various varieties of sweet orange (*Citrus aurantium*) also contains sufficient nitrogen compounds for the primary fermentation by yeast. It has been found possible to produce fermented juice containing as high as 17-18% of alcohol by volume from sweetered orange juice with suitable pure strains of *Saccharomyces ellipsoideus* and without the addition of any nitrogen compound. Further, fresh orange juice was found to contain nitrogen compounds in an amount equal to or even greater than the minimum requirements as stated by Lindner (6) for optimum fermentation

It was noticed, however, that when sweetened orange juice was sterilized under pressure by heat, it lost much of its organic and also a considerable portion of its ammoniacal nitrogen. Grape juice similarly treated also lost some of its organic nitrogen, but the loss in this case was much less than in the case of orange juice. This may be due to greater heat stability of the organic nitrogen compounds contained in grape juice This loss of nitrogen in orange juice in no way interferes with the primary stage of fermentation induced by yeast cells, as here again alcohol percentages of 17-18% by volume could be obtained on fermentation. But the subsequent stages of the life cycle of the yeast cells seemed in this case to be very greatly deranged. This was very clearly noticed when the so-called 'sherry' yeasts were employed. These yeasts after completion of the main fermentation pass into the film-forming and oxidative stage (7, 8), which is characterized by the tendency to form a film on the surface and a mild oxidation of the substrate by the yeast cells. The shape and arrangement of the yeast cells as seen under the microscope also change to a certain extent This is particularly noticeable in the case of 'sherry' yeasts and is also met with, to a lesser degree, in the case of other varieties of *Saccharomyces ellipsoideus*. The 'film-forming' and

'oxidative' stages were not noticed when sweetened orange juice, heat-sterilized under pressure, was employed and this may be due to the lack of sufficient nitrogen in a suitable form. Since 'heat sterilization' processes are sometimes employed in the fermentation of fruit juices, it was thought desirable to investigate how far the nitrogen content of sweetened orange juice is lost during 'heat sterilization' under different conditions

The juice of Valencia and Washington Naval variety of oranges was employed as raw material. The sugar used for sweetening was pure crystal cane sugar whose organic and ammoniacal nitrogen contents were determined separately and found to be insignificant. The increase in volume of the juice due to the sweetening has been allowed for in compiling the results This increase in volume was experimentally found to be about 12% when 20 gms. of cane sugar were dissolved in 100 c.c. of the juice of density of 8·5° Bx Analytical procedures laid down by the Association of Official Agricultural Chemists of America (1935) have been followed throughout the analysis.

As was expected, preservation of orange juice, raw or sweetened, by processes not involving the application of heat, had no effect on the nitrogen content of the juice (Table I)

TABLE I.

	Freshly expressed Juice I	Freshly expressed Juice II	Preserved Juice I	Preserved Juice II.	Preserved Juice III
Ammoniacal and organic nitrogen %	0 077	0 081	0 071	0 078	0 081
Ammoniacal nitrogen %	0 014	0 012	0 010	0 014	0 010
Organic nitrogen % (by difference) .	0 063	0 069	0 061	0 064	0 071
Proteins % (organic nitrogen × 6 25)	0 394	0 431	0·381	0 400	0 444

For determining the effect of heat, both fresh and chemically preserved orange juice was sweetened with 20% pure cane sugar and 'heat sterilized' in different ways. Pure juice from ripe 'Sultana' grapes was treated similarly. The results are recorded in Tables II, III and IV.

TABLE II

(Fresh Orange Juice)

	Original	Sweetened and sterilized at 15 lbs /20 mts	Sweetened and sterilized at 15 lbs /20 mts.	Sweetened and sterilized at 20 lbs /20 mts.
Ammoniacal and organic nitrogen % .. .	0·081	0 009	0 005	0 002
Ammoniacal nitrogen % .	0 012	0 007	0·004	0 002
Organic nitrogen % (by difference) . ..	0·069	0 002	0 001	0 00
Proteins % (organic nitrogen × 6·25)	0·431	0·012	0·006	0·00

TABLE III

(Chemically Preserved Orange Juice.)

	Original	Sweetened and sterilized at 15 lbs /20 mts	Sweetened and sterilized at 15 lbs /20 mts
Ammoniacal and organic nitrogen % .	0 077	0 004	0 005
Ammoniacal nitrogen %	0 014	0 002	0 003
Organic nitrogen % (by difference)	0 063	0 002	0 002
Proteins % (organic nitrogen × 6 25)	0 394	0 012	0 012

TABLE IV.

(Pure Grape Juice)

	Original	Sweetened and sterilized at 15 lbs /20 mts
Ammoniacal and organic nitrogen %	0 070	0 055
Ammoniacal nitrogen %	0 010	0 007
Organic nitrogen % (by difference)	0 060	0 048
Proteins % (organic nitrogen × 6·25) .	0 375	0 300

Sterilization of sweetened orange juice at 15 lbs. therefore destroys more than 80% of the organic nitrogen and also a considerable portion of the ammoniacal nitrogen. In pure grape juice the loss is not so great, only 20% of the organic nitrógen being lost.

In a further series of experiments sweetened orange juice was 'heat sterilized' in four different ways and the analytical data are given in Table V

TABLE V

	Original.	Sweetened and pasteurized at 92-95°C. for 20 minutes.	Sweetened and steamed at 0 lbs for 15 minutes.	Sweetened and sterilized at 10 lbs for 10 minutes	Sweetened and sterilized at 10 lbs. for 15 minutes
Ammoniacal and organic nitrogen %	0 077	0 070	0 063	0 040	0 030
Ammoniacal nitrogen % ..	0 014	0 010	0 008	0 007	0 007
Organic nitrogen % (by difference) ..	0 063	0 060	0 055	0 033	0 023
Proteins % (organic nitrogen × 6 25) ..	0·394	0 375	0 344	0·206	0 144

It is therefore obvious that the destructive action of heat on the nitrogen compounds contained in the sweetened orange juice depends upon the severity of this heat treatment. Pasteurization alone does not alter the nitrogen content very much, whilst autoclaving at 10 lbs. pressure decreases it by about 50% and at 15 lbs. pressure by over 80%. The duration of the 'heat sterilization' also has a significant influence. The loss of organic nitrogen is more

marked than the loss of ammoniacal nitrogen though both losses are considerable.

When sweetened orange juice which had lost much of its organic nitrogen through ' heat sterilization ' under pressure was fermented, its nitrogen content was found to increase once again. This increase is practically entirely due to the increase in organic nitrogen, the ammoniacal nitrogen being hardly affected. Sweetened orange juice was autoclaved in a cotton plugged flask at 15 lbs. pressure for twenty minutes. A portion was aseptically withdrawn for analysis The rest was inoculated with a pure strain of *Saccharomyces ellipsoideus* and fermented at 25°C. Portions were aseptically withdrawn at various intervals for analysis (Table VI).

TABLE VI

	Sweetened and auto-claved juice original	After 1 day's fermentation	After 4 days of active fermentation	After 8 days of active fermentation	After fermentation was nearly complete (12 days).
Ammoniacal and organic nitrogen %	0 004	0 006	0 045	0 067	0 070
Ammoniacal nitrogen %	0 003	0 003	0 004	0 004	0 004
Organic nitrogen % (by difference) .	0 001	0 003	0 041	0 063	0 066
Proteins % (organic nitrogen × 6 25)	0·006	0 018	0 256	0·394	0 412

That the above apparent increase in organic nitrogen is due to soluble organic compounds and is not merely due to suspended yeast cells is apparent from the analysis of clarified fermented orange juices (Table VII). After completion of the active fermentation the fermented juice was settled and decanted off, and repeatedly filtered through paper on which a siliceous filter-aid like ' Hyflo super-cell ' had been deposited, till it was perfectly clear. The slight increase in the ammoniacal nitrogen in these clarified samples is probably due to the uptake of soluble ammoniacal compounds from the filter-aid.

TABLE VII.

(*Clarified Fermented Orange Juices*)

	I	II.
Ammoniacal and organic nitrogen %	0 069	0·060
Ammoniacal nitrogen %	0·011	0 012
Organic nitrogen % (by difference) ..	0 058	0 048
Proteins % (organic nitrogen × 6 25)	0·362	0·300

The increase in organic nitrogen during fermentation of orange juice is therefore due to some synthesis of soluble organic compounds by the yeast cells. Since the yeast cells in such fermented orange juices still failed to show any films or any signs of oxidation, it would appear that organic nitrogen, at least the organic nitrogen compounds synthesized by the yeast, are not available for its own metabolic activity in the ' after-fermentation ' stage. The addition of ammoniacal nitrogen would therefore seem to be desirable

at this stage This is in accordance with the observation of Müller-Thurgau and Hopkins (9, 10), who found that those nitrogen compounds are most easily assimilated by the yeast cells which easily split off nitrogen in the form of ammonia. This does not prove that lack of ammoniacal nitrogen is responsible for the absence of the 'film-forming' and 'oxidative' stage in the above case There may be some specific inhibiting substance produced during the 'heat sterilization' under pressure But this is doubtful because grape juice retains much of its original nitrogenous matter on similar 'heat sterilization' and in the 'after-fermentation stage' of such a juice, the film is easily formed and oxidation changes take place Lack of nitrogen in an easily assimilable form may at least be a contributory factor

My best thanks are due to Prof J N Ray, University Professor of Organic Chemistry, Lahore, under whose direction this investigation was conducted and to Messrs The Indian Mildura Fruit Farm Ltd for a scholarship

SUMMARY.

1 Fresh orange juice contains sufficient nitrogen in an easily assimilable form for the primary fermentation by *Saccharomyces ellipsoideus.*

2. 'Heat sterilization' under pressure destroys most of the organic and much of the ammoniacal nitrogen compounds in sweetened orange juice, the amount lost depending upon the pressure employed and the duration of the treatment Pure grape juice under similar conditions suffers this loss to a much less degree

3 The primary fermentation is not appreciably hindered by the above loss in nitrogen compounds, but the 'after-fermentation stages', namely those of film-formation and oxidation, are in this case inhibited

4 During fermentation the organic nitrogen content of the juice again increases, probably as a result of synthesis by the yeast of soluble organic nitrogen compounds. But these compounds do not seem to be available for the secondary changes, during the 'after-fermentation stage', induced by the life cycle of yeast

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A BIOCHEMICAL INVESTIGATION OF THE TUBERCULATION OF WATER PIPES

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(Communicated by Prof V. Subrahmanyan, D Sc , F I C , F.N.I)

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CONTENTS.

I. INTRODUCTION ·

THE PROBLEM OF TUBERCULATION IN WATER ENGINEERING.

The changes that occur and the types of deposits that form inside the water mains and reservoirs are diverse ; and the nature of investigation and the method of treatment will depend on the change in the character of water or the nature of deposit which may have been observed. 'Slimy ferruginous streamers', 'ferruginous tubercles', the 'spongy disease of iron', and 'calamity growth' or the 'Brunnen-pest' as it is better known on the continent, are the commonly met with obstructions in service pipes and storage reservoirs, the result being the efficiency of their service suffers considerably. But the phenomenon of tuberculation is of more common occurrence and is perhaps one of the greatest difficulties that confront the water works engineer. In recent years, with the increasing usage of cast iron pipes—by reason of their many advantages over other types of pipes—the problem has become increasingly acute.

The formation of nodular excrescences or tubercular incrustations on the innerside of pipes is known as tuberculation. These nodules or tubercles make their appearance very shortly after the installation of the pipes, and

they begin as minute dotted projections of a roughly limpet shape. They grow by the accretion of concentric layers and ultimately coalesce to give a layer up to one and a half inches thick or even more (Fig 1).

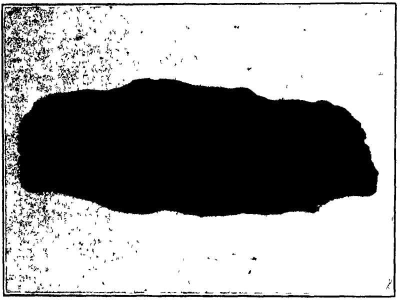

FIG. 1. A tubercle (about 11 years old)

Reduction of carrying capacity and consequent difficulties —As tuberculation sets in, the interior surface of the pipe naturally becomes roughened and a considerable amount of ineffective velocity is developed. Even an isolated tubercle is often as bad as a number of them grouped together. Sometimes it may be even worse. Scobey (1930) observed that an occasional obstruction has greater effect on the pipe flow than might be expected from the continued effect of a number of obstructions ; and the obstructions such as rivet heads, plate offsets, blisters, tubercles, etc., have a much greater influence than would appear to the naked eye. Clark (1930) calculated that a nodulation under certain rates of flow might be considered to reduce the available effective or working area of a pipe to five times the height of the nodule, *i e.*, a reduction of 6 per cent in area by nodulation reduces the effective area by at least 44 per cent and the carrying capacity by approximately 50 per cent.

The tubercles grow steadily, and ultimately coalesce. Finally, the pipes suffer considerable diminution in the diameter of the bore and the tubercles, therefore, cause considerable loss by effectively reducing their carrying capacity.

TABLE I.

*The progressive rate of reduction of carrying capacity of pipes (the coefficient of discharge c) due to tuberculation in course of time (Hazen and Williams, 1933.)**

Size of pipe (in inches)	No of years in which the coefficient c gets reduced from 130 to 60				
	Coefficient c				
	130	120	100	80	60
	No of years required				
4	0	4	13	26	45
5	0	4	14	28	50
6	0	4	15	30	55
8	0	5	16	33	62
12	0	5	17	37	,,
18	0	5	18	40	,,
24	0	5	19	42	,,
30	0	6	19	43	,,

* Hazen and Williams have derived a formula, known as the *Hazen and Williams' Formula* (Angus, 1931), from the results of their extensive studies of the flow of water in pipes and channels used in water works service The formula is

$$v = 1\,319\, c r^{63} s^{54} = 1\,319\, c r^{13} s^{04} \sqrt{rs}$$

where $v =$ velocity, $c =$ coefficient of index of the smoothness of the interior of the pipe surface, $r =$ circumference/area, and $s =$ sine of the slope

This formula is the most commonly accepted one for calculating discharge from cast iron pipes

Thus, given the age of a pipe and its diameter, from the foregoing table the reduction of its carrying capacity may be approximately reckoned In practice, however, a higher loss in capacity is observed Haydock (1924, 1935), White (1932), Downer (1933), Sherman (1934) and others have recorded a greater reduction for relatively shorter periods Particular mention may be made, in this connection, of the report of the committee on the pipe line friction coefficients of the New England Water Works Association (1935) which concludes that the average loss in capacity of an iron pipe after 30 years of service is considerably higher than that predicted in the Hazen-Williams tables (*loc cit.*) The author's experiences with the Trivandrum Water Works, the Madras Water Works and the Bangalore Water Works (South India) show that a still higher loss in capacity is effected after a relatively short period of service. He has examined specimens of pipes which are 35 to 40 years old in which the tubercles have so thoroughly choked the pipe that one end of the pipe could not be seen from the other end. These pipes had, of course, to be discarded (Figs. 2 and 3)

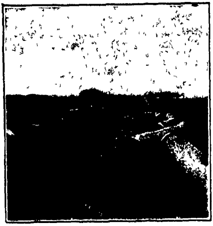

FIG. 2. Pipes which have been in service for about 40 years are taken out and discarded because of tuberculation.

FIG. 3. One of the pipes in the above pipe line showing the tuberculated condition—practically choked with the result that the other end cannot be seen

From the foregoing and other observations, it becomes clear that, in addition to causing a considerable diminution in the bore of the pipe and consequently affecting the accuracy of meters, tuberculation produces a softening effect on the iron and makes this material still more susceptible to the forces of disintegration.

The economic loss resulting from tuberculation.—A conservative estimate would indeed show that the annual loss to the world through repairs, replacements and loss of energy would amount to several millions pound sterling.

The deterioration by tuberculation of cast iron water mains of the Sydney Metropolitan Water and Sewage Board (1932) has resulted in an annual loss of £225,000 and heavy maintenance costs. The expenses incurred by the Bangalore Water Works for 1933 for replacing a large quantity of 1½ inches and 2 inches G. I. pipes and C.I. pipes service, and for reconditioning of the roads incidentally cut open, amount to Rs.95,000. Lohr (1929), Baylis (1930) and others have also dealt with the economic aspect of the problem

The vast economic loss resulting from tuberculation has, therefore, led to extensive investigation of its cause and, more particularly, of practical methods for its prevention. In spite of this, the available scientific information regarding the causation and development of tubercles is comparatively meagre

Theories regarding the origin of tubercles.—Brown (1903-4) found that while some of the nodular incrustations contained iron bacteria like *Gallionella* and *Spirophyllum*, many other specimens were free from every trace of life Casagrandi (1913) on the strength of his own observations came to the conclusion that iron bacteria do not exert any apparent influence on the formation of tubercles Subsequent workers like Binaghi (1913), Sette (1932) and Sherman (*loc. cit.*) are also inclined to think that the formation of tubercles is a purely chemical phenomenon

As contrasted with the above, Schorler (1904) postulated that ferruginous organisms must be held responsible for a large part of incrustations that appear in conduit pipes and reported that *Gallionella* is a causative organism Most of the later workers, Moesz (1930, 1931), Reddick and Linderman (1931), Herrmann (1932), Hammond and Goffey (1932), Naumann (1933), Downer (1933) and others have supported Schorler's views and have recorded that tuberculation is due to the activities of iron bacteria like *Leptothrix*, *Gallionella* and *Spirophyllum* These workers, especially Reddick and Linderman and Downer, base their conclusions largely on mere observation of certain similarity between the composition of tubercles in water pipes and that of bog ores

It may thus be seen that conflicting views are held with regard to the mode of origin and development of tubercles. In the first place, there is no general agreement that the iron of the tubercle comes entirely from the pipe, for some workers hold that the surrounding water also supplied its contribution of iron. Again, while some maintain that the formation of tubercles is purely a physical and chemical phenomenon, others adduce facts to show that iron bacteria influence the formation.

It is obvious, therefore, that the mechanism of formation of tubercles has not been systematically worked out, with a view to offering a complete explanation of their formation under all circumstances, and to suggest preventive methods based on more scientific data. There is a great need, therefore, for a systematic inquiry into the problem and to investigate methods of preventing, or at any rate reducing to a minimum, losses through tuberculation.

The present paper relates to a detailed investigation of the problem with particular reference to the Trivandrum Water Works with which the author

has been intimately connected ever since the time of installation of the pipes for water distribution The observations made on the occurrence, composition and structure of tubercles, the experiments carried out over a period of four years on the mode of formation of tubercles, the rôle of bacteria in the process of tuberculation, and the results of experiments on the prevention of tuberculation—these and related subjects have been discussed in the present communication

II OBSERVATIONS ON THE OCCURRENCE COMPOSITION AND STRUCTURE OF TUBERCLES IN THE SERVICE MAINS AND DISTRIBUTION PIPES

The following observations relate to the Trivandrum Water Works which were opened in December 1933 All the mains and distribution pipes having been previously properly cleaned and brushed out and well protected from contamination during the laying process and further sterilised in the usual manner, started working from the 11th of December The distribution system was put to regular service and it began to draw at the rate of three to five million gallons of water per day for the public of Trivandrum

Occurrence of Tubercles —In April 1934 while flushing the mains in a certain part of the distribution system one of the scour valves was found for the first time to discharge water of a reddish brown colour which is generally known as red water' An investigation of the whole distribution system and all the filter units was therefore undertaken A few of the strainer tubes header pipes and ordinary pipes taken out on the next day from the filter units and distribution system showed that tubercles were forming or just formed In some pipes particularly in some of the strainer tubes and header pipes exposed tuberculation was just setting in These tubercles looked like blisters in shape and appearance having a height of about ¼" They were found to be slightly more broad than high and in some places they had become rather confluent It was also observed that they were spaced at irregular intervals of two to three inches both ways in the case of smaller pipes A more important observation made in regard to the distribution of tubercles in bigger pipes was that the tubercles (which were making their appearance) were practically confined to the two sides of the pipe the crown and the invert having very little tuberculation

With a view to studying the nature and extent of tuberculation in the whole distribution system and also finding out the relation between the process of tuberculation on the pipe surface and the surrounding water in the pipe a detailed programme for systematically cutting out the pipes under aseptic conditions (without causing any traffic difficulties or any public nuisance), was chalked out Chemical and bacteriological examination of the water flowing through these pipes was also carried out every day For sampling purposes, the different parts of the water system were significantly chosen with a view to study the influence of different conditions in the same pipe

system, namely the effect of raw water, chemically treated water and finally purified water on the formation of tubercles (Fig. 4).

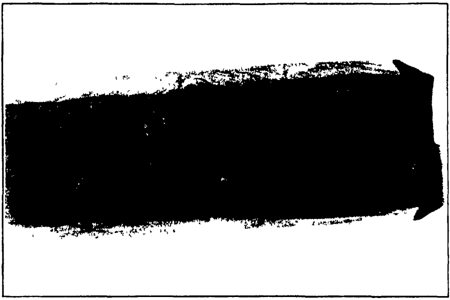

FIG 4. A handy specimen of a tuberculated pipe cut out from the Trivandrum water distribution system. The pipe belonged to the town distribution system and was carrying purified and chlorinated water The pipe was in service for about 18 months

Classification and comparative description of the different types of tubercles collected from the entire pipe system.

Classification of the tubercles —The tubercles collected may be classified into three types (1) those collected from the mains carrying raw water, (2) from the pipes containing treated water and (3) from the town distribution system containing drinking water Although the age of the tubercles was practically the same in all the cases, they showed considerable individual variations. Speaking generally, the extent of tuberculation in the different sections may be placed in the following order (i) mains in the distribution system carrying the finally purified water, (ii) pipes containing the treated water and (iii) those conveying raw water

Comparative description of the tubercles —The tubercles from the distribution mains were the biggest (average ½" at the base and ½" in height) They were of a reddish-brown colour and of an earthy odour The pipes containing treated water had smaller tubercles which were dull brown in colour and had a damp, earthy smell The tubercles in raw water pipes were the smallest. They were dark brown or black, and the odour was almost like that of the back-water sludge. These physical differences of the tubercles would indicate that treatment and purification of water accelerate the process of tuberculation

to some extent. It is possible, however, that the natural equilibrium of raw water may have been disturbed by the chemical treatment and made aggressive in a manner to facilitate the process of nodulation, and this is especially so in the case of soft water.

The general characteristics of these tubercles —In all other respects the different sets of tubercles were alike. They had more or less the same type of appearance, having a flat bottom and a more or less conical shape; and they appeared as though they had grown from the inside of the pipes. Notwithstanding the varying shades of colour they had (from pale to deep dark brown) when freshly taken out, all of them, on drying, changed to deep red brown of ferric oxide. When examined longitudinally, it was found that each tubercle was made up of black and brown layers and the latter, which were thicker, contained ferric iron, while the former which occurred in thin layers contained either ferrous or ferroso-ferric iron Taken as a whole, the tubercles had magnetic properties, on closer examination, it was found that the reddish layer (Fe_2O_3) was not magnetic, while the blackish layer (Fe_3O_4) was highly magnetic.

Chemical analysis [1] *of the three different types of tubercles.*

The results of the analysis of the three types of tubercles are given in Tables II, III and IV respectively.

TABLE II.

Chemical composition of tubercles in the pipes carrying raw river water which has been treated with lime and allowed to settle for about 12 hours.*

(Percentage on dry weight)

Samples	Loss on ignition	Iron ferrous (FeO)	Iron ferric (Fe_2O_3)	Aluminium (Al_2O_3)	Silica (SiO_2)	Phosphorus (P_2O_5)	Manganese (MnO_2)	Calcium (CaO)	Magnesium (MgO)	Total nitrogen	Total carbon	Moisture content
I	9·2	6·7	67·9	6·2	6·6	0·1	0·6	1·8	traces	0·09	1·21	29·5
II	8·7	6·4	70·7	8·0	5·9	0·3	0·2	0·9	traces	0·11	1·22	34·9
III	9·2	8·2	72·0	7·5	3·9	0·2	0·2	0·6	traces	0·08	1·06	37·6
IV	8·8	7·4	71·5	6·8	4·3	0·3	0·4	0·8	traces	0·10	1·15	33·2
V	9·0	7·8	69·8	7·7	4·6	0·2	0·3	1·1	traces	0·07	1·09	34·1
VI	8·5	7·3	68·9	6·9	5·2	0·1	0·5	1·3	traces	0·06	1·0	32·6

* Collected from six different parts in the 30″ gravitation main conveying raw river water (but lime treated and settled) from the settling tank at the Aruvikara river side to the Trivandrum filter house, a distance of about eight miles.

[1] Methods for the estimation of most of the constituents were the same as prescribed by the A.O.A.C. (1930).

TABLE III.

Chemical composition of tubercles in the mains at the filter house containing purified water.*
(Percentage on dry weight)

Samples	Loss on ignition	Iron ferrous (FeO)	Iron ferric (Fe_2O_3)	Aluminium (Al_2O_3)	Silica (SiO_2)	Phosphorus (P_2O_5)	Manganese (MnO_2)	Calcium (CaO)	Magnesium (MgO)	Total nitrogen	Total carbon	Moisture content
I	8·8	3 7	69 5	7 6	6 0	0 2	0 2	1 3	traces	0·05	1·96	15 6
II	8 4	4 6	68 5	8 2	5 7	0 1	0 1	1 4	traces	0 05	1 65	17 4
III	7 9	3 6	69 9	7·2	5 8	0 2	0 3	1 5	traces	0 07	1 80	16 8
IV	8 2	4 5	70 2	6 9	6 3	0 1	0 4	1 4	traces	0 06	1 71	17 7
V	7 3	3 8	70 3	7 5	5 8	0 1	0 3	1 6	traces	0 06	1 84	15 9

* I. Collected from the northern dead end of the main containing filtered and chlorinated water, washing the filter units.

II Collected from the southern dead end of the main containing the same water.

III, IV and V. Collected at random.

TABLE IV.

Chemical composition of tubercles from the distribution system.*
(Percentage on dry weight)

Samples	Loss on ignition	Iron ferrous (FeO)	Iron ferric (Fe_2O_3)	Aluminium (Al_2O_3)	Silica (SiO_2)	Phosphorus (P_2O_5)	Manganese (MnO_2)	Calcium (CaO)	Magnesium (MgO)	Total nitrogen	Total carbon	Moisture content
I	12 8	3·1	68 7	9·8	3 1	0 4	0·2	0 8	traces	0 14	3 57	6 8
II	11 5	2·1	65 0	12 1	3 3	0 4	0 4	0 7	traces	0 20	5 28	36 8
III	11·7	2 4	66 0	12·7	3·4	0 3	0·7	0 7	traces	0·15	2·20	3 9
IV	10 9	3·2	67·4	10 8	2 9	0·2	0·6	0 8	traces	0 16	3 10	9 5
V	10 6	3 4	68·0	11 2	3·2	0 3	0·3	0 9	traces	0 20	3·20	10 0
VI	12 3	3 8	69 1	10·7	3 5	0 4	0 5	0 6	traces	0 19	2·80	15·2
VII	9 8	2·9	70 6	11·0	3·3	0·3	0·7	0 8	traces	0 18	3 0	14 8
VIII	10·3	3·5	70 0	10 6	2 8	0·3	0 6	0·7	traces	0 17	3·4	16 4

* Collected from eight different parts in the distribution system of the town supply.

It may be observed from tables II, III and IV that the tubercles—at any rate those in the same pipe system—have a more or less similar composition, except in the case of those present in that part of the distribution system containing the finally purified water where the percentage of ferrous iron is low and is much less than that in the tubercles present in the other parts

of the water system. This is due to the more rapid rate of oxidation of the ferrous iron of the tubercles formed in that part of the water system. Iron in the ferric condition is the chief constituent, while aluminium, ferrous iron, silica, calcium, magnesium, manganese and phosphorus are present in smaller proportions. Organic carbon and nitrogen are also present in smaller quantities.

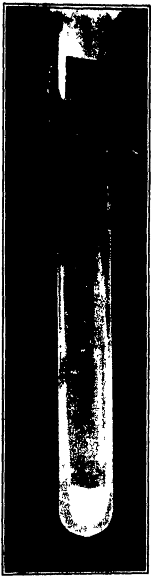

FIG. 5. Agar slant culture.

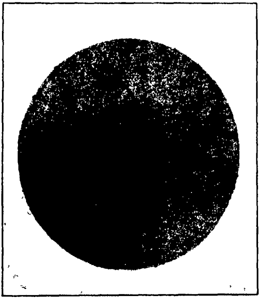

FIG. 6 Under the microscope: magnification about 1,200.

Pure culture of the new species of *Pseudomonas* occurring in the tubercles.

BACTERIOLOGICAL EXAMINATION OF TUBERCLES.

With a view to isolating and studying the microorganisms, if any, present in the tubercles, several media like nutrient agar, mineral medium, Van Debden's medium, wort agar, silt medium, specific media for iron bacteria and various other synthetic media were tried The examination of the tubercles did not reveal the presence of any of the better known iron bacteria such as *Leptothrix*, *Gallionella*, *Spirophyllum*, *Cladothrix* and *Crenothrix* The only form of life invariably encountered in all the tubercles was a lower form of fluorescent bacillus belonging to the genus *Pseudomonas* which can easily be isolated from the tubercles using the nutrient agar medium of *p*H 6 8 This organism has been completely characterized according to the methods of the committee on the pure culture study of bacteria (1930) and Bergey (1930), and it has been found to be a new species (Winogradsky, 1888 , Molisch, 1892, 1910 , Rullmann, 1912 , Mumford, 1913 , and Ellis, 1919) The pure culture studies on this organism are described below (Figs 5 and 6)

Description of the new species of Pseudomonas —

Rods. 1 3 by 1 6 to 1 6 by 1 9 microns , occurring singles , Gram negative , and not motile

Gelatin Stab No liquefaction , granular growth inside and surface also

Agar slant Luxuriant growth , faintly bluish

Broth. Very cloudy , turbid

Milk · Peptonization only

Potato Good growth , slimy, whitish

Indol not formed

Nitrates and Nitrites No reduction.

Sugars. No change in lactose, glucose, levulose, sucrose, dulcite, inulin, mannite. There was growth in these

Aerobic: facultative

Optimum temperature · 30°C

Habitat · Isolated from the tubercles , it was isolated from the water passing the tuberculated pipes also

The bacterium is tentatively named *Pseudomonas ferrugineum* (Pillai)

Chemical analysis[1] *of water flowing through tuberculated pipes* —The results are given in Table V.

[1] Examination of water was carried out according to the standard methods recommended by the American Public Health Association (1933)

TABLE V.

Chemical examination of the representative samples of raw water and water passing through different tuberculated pipes

Samples	pH	Parts per 100,000												Degrees		
		Free ammonia	Albuminoid ammonia	Nitrate	Nitrite	Chlorides	Oxygen absorbed in 3 mins	Oxygen absorbed in 4 hrs	Dissolved oxygen	Total solids	Loss on ignition	Al	Fe	Total hardness	Temporary hardness	Permanent hardness
I	6·9	0·005	0·003	0·016	Nil	0 76	0·084	0·160	0·50	35·8	31·60	traces.	0·10	2·54	1·54	1·00
II	7·8	0·004	0·002	0·024	Nil	0·76	0·088	0·136	0 63	14·8	6·05	traces.	0 10	2·02	0·92	1·10
III	7·5	0·003	0·002	0·022	Nil	0·92	0·075	0·145	0·72	11·40	7·60	traces.	0·15	1·76	0·87	0·89
IV	7·5	0·002	0·002	0·022	Nil	0·95	0·062	0·120	0·70	8 50	5 12	traces.	0·17	1·40	0·71	0·69

Sample No. I. Raw river water, *i.e.*, the source of water supply for Trivandrum town.
Sample No. II. The same water but treated with lime and allowed to settle for about 8 hours.
Sample No. III. The same water that has been filtered but not chlorinated.
Sample No. IV. The same water filtered and chlorinated, representative of the street tap water.

It may be seen from the foregoing table that the composition of the filtered water has not been adversely affected by the tuberculated condition of the pipes. There was a slight increase, however, in the iron content which was even higher than that in the original raw river water. This would suggest that (1) a part of the iron of the pipe had passed into the filtered water, and (2) the iron of the tubercle was not derived from the water passing through it, but from the pipe itself.

It is difficult to state whether the slight increase in the quantity of iron is inimical to public health. It is known, however, that more than traces of iron cause constipation and other disorders in those who habitually drink it. This is particularly so when the water assumes the reddish tint that gives rise to 'red water'. The water then acquires an inky taste and leaves a bad stain on clothes when used for laundry purposes.

The increasing iron content of the water brings us to another problem, *viz*, the corrosion of the pipes during service. The extent of corrosion by different waters and the influence of various factors such as dissolved oxygen, carbon dioxide and chlorine have been studied by a number of workers. In the present enquiry, the observations were confined to the relation of corrosion to tuberculation of pipes.

Bacteriological examination of the water.—The results are given in Table VI.

TABLE VI

Bacteriological examination of raw water and the water passing through different tuberculated pipes.*

Sample	Number of colonies on nutrient agar per c c. at 37°C. after 24 hours	Number of colonies on nutrient agar per c c. at 37°C after 48 hours	Acid and gas production in lactose Mc broth (volume of water in c c)	Acid and gas production in glucose Mc broth (volume of water in c c)
1.	320	730	−0·1, −1, −5, +10, +20, +50 +100	−0 1, −1, +5, +10, +20, +50, +100
2	280	660	−0 1, −1, −5, −10, +20, +50, +100	−0·1, −1, +5, +10, +20, +50, +100
3	30	340	−0·1, −1, −5, −10, −20, +50, +100	−0·1, −1, +5, +10, +20, +50, +100
4	20	230	−0·1, −1, −5, −10, −20, −50, +100	−0·1, −1, −5, +10, +20, +50, +100

* The same samples as were used for chemical examination.

It may be observed that the quality of the water at different stages was highly satisfactory. The total number of bacteria was comparatively small. The absence of lactose fermenters from quantities up to 50 c.c showed that the water was quite safe for drinking purposes It is of interest to note that the organism which has been found to be present in the tubercles has also been easily isolated from samples 2, 3 and 4 It is present in water in very small numbers only

Examination of unused pipes.—Handy pieces of unused pipes were cut and examined under the *Greenough dissecting microscope* The examination showed (1) the surface of the interior walls was rather rough, and (2) the protective coating of the tar or asphalt on the inside of the pipe was imperfect, *i e.*, points of bare iron could be made out These two conditions possibly promote corrosion of pipes and subsequent tuberculation The chemical analysis of the impurities in the pipe material is given in Table VII.

TABLE VII

Chemical analysis of the impurities in the unused pipe which is of the same brand as the used pipe

	Percentage
Total carbon	3 60
Graphitic carbon	2 85
Combined carbon	0 75
Silica (SiO_2)	2 30
Manganese (MnO_2)	0 50
Phosphorus (P_2O_5)	0·30

Examination of tuberculated pipes —The examination of these under the *Greenough dissecting microscope* revealed the conditions after corrosion and tuberculation had set in (Fig. 4) The following points may be of interest: (1) the tubercles were scattered on the inner surface chiefly at points where the iron of the pipes was exposed due to imperfect coating or otherwise, and (2) closer examination of the portion where a tubercle had developed revealed that corrosion had taken place there These would show that the necessary iron for the formation of tubercles comes largely from the pipe itself

III. THE RÔLE OF THE ASSOCIATED ORGANISM (TENTATIVELY NAMED *PSEUDOMONAS FERRUGINEUM*) IN THE FORMATION OF TUBERCLES.

From the foregoing studies, the following facts have emerged: (1) that iron in the ferric condition is the chief constituent of the tubercle and comes presumably from the pipe itself, and (2) that the tubercle is invariably associated with a lower form of fluorescent bacillus of the *Pseudomonas* type (*Pseudomonas ferrugineum*) which is derived from the water. It may also be

noted that both the inner surface of the pipe and the water in contact with it are equally operative in the process of tuberculation.

A tubercle may, therefore, be defined as a well preserved mass of the corrosion products of the pipe material combined with the contributions of the surrounding water in the pipe It is not clear, however, how these constituents become a compact, limpet-like structure and stand out so prominently and persist in spite of a regular current of water.

With a view to throwing some light on this important point, some preliminary experiments were carried out with pieces of cast iron pipes, with and without a protective coating It became clear that tubercles appear at points bare of the coating already exposed or where, as often happens, the protective coating has been removed by the flow of water. A coating of tar or asphalt does offer some protection but that would appear to be only temporary. Even small points in the coating through which the iron is exposed are sufficient to start rusting which will soon be followed by tuberculation Rusty layers do not, however, assume any definite proportions. They can be and are often partially flushed out by a vigorous stream of water. Tubercles, on the other

Experimental demonstration of the action of the associated organism in the formation of tubercles

B A

FIG. 7. B (containing a heavy culture of the new species of *Pseudomonas*) showing the rapid formation of tubercles; whereas the control A (devoid of those organisms, otherwise under same conditions) showing no tuberculation.

hand, have definite conical or dome-like shapes and grow out prominently and persist even when a strong current of water is flowing through the pipes. This remarkable behaviour, as well as the ultimate production of the characteristic structure and shape of the tubercle, it was thought, might bear some relation to the occurrence of the organism which flourishes in the rusty layers of the tubercle.

With a view to throwing further light on these aspects of the problem, the following experiments were carried out.

The actual behaviour of the organism in the tubercle.—(1) Pieces of cast iron pipes were cut into convenient sizes and dropped into bottles (Fig 7) which were connected; while one of these (A) contained distilled water only, the other (B) contained an equal quantity of the same water and also a heavy culture of the new organism; otherwise the conditions (air supply, etc.) were the same. The water in the bottles was continuously stirred by using a suction pump.

It was observed that tubercles soon appeared and developed in the case of (B), whereas in the case of (A) the water turned brown and the iron hydroxide in a colloidal condition was subjected to a continuous movement due to the stirring of the water, the pipe piece having a rather clear surface. After a period of 5 to 6 weeks, the apparatus was dismantled and the pipe pieces were taken out The pipe in the bottle (A) containing no organism showed no tuberculation at all, while the other pipe, *i e*, bottle (B) containing the organism showed heavy tuberculation

(2) A more elaborate experiment was next carried out An apparatus was arranged, wherein the conditions have a nearer approach to those in a regular water distribution system There were three pairs of fairly large bottles, each pair being placed at different levels and the two bottles being connected by a glass tube containing a longitudinal section of small pipe; and three types of water (waters of different composition) were made to flow in the three different systems: *A* containing sterilised water only, *B* containing ordinary water and *C* containing sterilised water with a heavy culture of the new organism. The same water in each case was circulated again and again, taking all the necessary precautions.

After a few days it was observed that in the case of *A*, although there was intensive rusting of iron, there was absolutely no tuberculation. The insoluble iron oxide used to accumulate in the bottle placed at the lower level. In the case of *B*, on the pipe surface, blisters and vesiculations first occurred and small tubercles were slowly developed; while in the case of *C*, tuberculation set in rapidly and the entire surface became studded with tubercles of a much larger size than in the system *B*. Since the water in all these cases was found to be rather stagnant after a period of 10 to 12 weeks, the apparatus was dismantled. The tubercles from the *B* and *C* systems were carefully taken out and analysed chemically and bacteriologically and the results are shown in Table VIII.

TABLE VIII

Analysis of the tubercles prepared in the laboratory*

Samples	Loss on ignition	Iron ferrous (FeO)	Iron ferric (Fe_2O_3)	Aluminium (Al_2O_3)	Silica (SiO_2)	Phosphorus (P_2O_5)	Manganese (MnO_2)	Calcium (CaO)	Magnesium (MgO)	Total nitrogen	Total carbon	Moisture content
I	9 1	1 9	72 4	Nil	0 5	traces	0 1	Nil	Nil	0 10	1 8	18 2
II	10 5	0 8	75 6	Nil	0 9	traces	0 2	Nil	Nil	0 15	2 5	19 5

* I: Tubercles from the system *B*
II Tubercles from the system *C*

From the foregoing table, it will be clear that the chemical composition of the two sets of tubercles is the same and they compare well with that of the naturally occurring tubercles. But it was, however, observed that the quantity of ferrous iron in the *C* tubercles is about half of that present in the *B* tubercles. This shows that the comparatively large number of the *Pseudomonas* bacillus present in the *C* system facilitates the oxidation of ferrous iron by the local concentration of oxygen and carbon dioxide

Bacteriological examination of these two sets of tubercles showed that, in both these cases, the new organism was found to be present in large numbers, but in the case of *C* they were present in the largest numbers

From the experiments described above, it may be concluded that the new species of *Pseudomonas* (*Pseudomonas ferrugineum*) plays a definite part in the formation of tubercles. From the very beginning of the changes that happen to the iron of the pipe, this organism leaves the water and goes into the flocculent mass of colloidal iron hydroxide and flourishes in the complex with the result that the whole mass is stuck on to the surface of the pipe over the corroded point or portion. The soft and spongy mass of iron oxide and the accompanying constituents from the pipe and the water would have been washed off with the current of water but for the entrance of these bacteria into the mass of the corrosion products and their further quick multiplication, thereby providing an extremely sticky or mucilaginous material of their bodies; and the inevitable result being, the rusty layers at the corroded point are effectively retained to develop into a nodular structure which tenaciously attaches itself to the pipe. In other words, these bacteria form an effective cementing material for considerably strengthening the different constituents of the tubercle and, at the same time, they actively multiply inside the soft and spongy masses of iron oxide in the same manner as the *Radicicola* bacteria multiply in the root system of leguminous plants and give rise to nodules.

In addition to the cementing function and the function of contributing the characteristic form and shape of the tubercles, these bacteria promote the oxidation of the ferrous iron surrounding them by the local concentration of their metabolic products, particularly carbon dioxide and oxygen which also facilitate further corrosion of iron.

IV. THE MECHANISM OF TUBERCULATION

From the above observations, it becomes clear that tuberculation is, to start with, a fundamental phenomenon of corrosion of iron, the chief material of the pipe, and subsequently it is subjected to the influence of the activities of the bacterium already described.

The principal changes that the iron of the pipe undergoes prior to tuberculation.—The water, carrying oxygen, carbon dioxide, chlorides and other important corrosive elements attacks the exposed iron of the pipe, and the principal changes the iron undergoes thereby may broadly be outlined as follows :—

The water in the pipe carries oxygen which attacks the iron of the pipe as it gets exposed and ferrous hydroxide is formed.

$$Fe+2\ H_2O \rightarrow Fe\ (OH)_2+H_2 \qquad \text{.. (1)}$$

The ferrous hydroxide will not, under ordinary circumstances, be precipitated as such, being comparatively soluble, but it soon combines with further oxygen yielding ferric hydroxide.

$$4\ Fe\ (OH)_2+O_2 \rightarrow 2\ (Fe_2O_3.\ H_2O)+2\ H_2O \qquad \text{.. (2)}$$

The ferric hydroxide first appears in colloidal solution, but is finally precipitated at appreciable distance from the metallic surface and this mass would have been carried away by the flowing water but for the presence of the bacteria which holds this material on to the surface of the pipe

Thus the first layer of ferrous hydroxide is oxidised to ferric hydroxide and a fresh layer of ferrous hydroxide is formed at the bottom to get oxidised, and as this process is going on, in between the yellowish brown or brownish layers of ferrous and ferric, a thinner layer of black ferroso-ferric oxide is also formed.

$$Fe+2\ FeO\ (OH) \rightarrow Fe_3O_4+H_2 \qquad \text{.. (3)}$$

Side by side with this process of oxidation, the iron in the pipe is also attacked by carbon dioxide in the water, forming ferrous carbonate with evolution of hydrogen.

$$Fe+H_2O+CO_2 \rightarrow Fe\ CO_3+H_2 \qquad \text{.. (4)}$$

By the absorption of more CO_2, the ferrous carbonate is changed to the bicarbonate.

$$Fe\ CO_3+H_2O+CO_2 \rightarrow Fe\ (HCO_3)_2 \qquad \text{.. (5)}$$

The bicarbonate is changed to ferrous hydroxide,

$$Fe\ (HCO_3)_2 \rightarrow Fe\ (OH)_2+2\ CO_2 \qquad \text{.. (6)}$$

and by further oxidation of the ferrous hydroxide it is converted into ferric hydroxide

$$2\,Fe\,(OH)_2+2H_2O\rightarrow 2\,Fe\,(OH)_3+H_2 \quad . \quad . \quad (7)$$

A large mass of ferric hydroxide is thus accumulated by the combined action of oxygen and carbon dioxide on the iron of the pipe The extraneous elements such as alum and lime which are used for the chemical treatment of the water, as also the natural constituents of the water, go to make up the bulk of the tubercle

The reaction of the water bacteria, in general, to the above chemical changes and the exact part played by the specific organism in the mechanism of tuberculation—As the chemical changes are proceeding in the above manner, a few species (which have also been identified, but found to be the commoner types of water bacteria), together with the specific organism *Pseudomonas ferrugineum*, get entangled in the rotted, spongy mass, consisting principally of ferrous, ferroso-ferric and ferric hydroxides The commoner types of water bacteria, unable to thrive in such a medium, steadily die out, while the specific organism alone survives and flourishes; and it multiplies and resides in each tubercle

The tubercle thus grows with the progressive accumulation of the corrosion products in concentric layers which are admirably preserved by the tenacious attachment of these bacteria, thus making it a suitable medium for its existence.

The several layers of the tubercle which are placed one above the other are sufficiently porous, so that water containing oxygen and carbon dioxide and also other corrosive elements have free access right to the very bottom of the tubercle to attack a fresh portion of the iron in the pipe

These various chemical and bacteriological processes start from the day the pipe begins working and all these processes go on continuously until the pipe is completely choked with tubercles and thus gets thoroughly useless.

V A METHOD OF PREVENTION OF TUBERCULATION BASED ON THE STUDIES OF THE PHYSIOLOGY OF THE SPECIFIC ORGANISM IN THE TUBERCLE.

A study of the various aspects of the problem of tuberculation, particularly the significance of the specific organism in the formation of tubercles, gave a clue to a method of treating the water so as to prevent tuberculation.

It was observed in the course of the studies on the formation of tubercles that the specific organism is quite necessary for the continued existence of the tubercles in the pipe system—to give them the characteristic form and shape, and hold them on to the pipe surface. This suggested that, if, by any means, the continued attachment of these organisms to the corrosion products could be prevented, the prevention of tuberculation could be achieved easily. It has, of course, always been borne in mind that the quality of the drinking water should be maintained at any cost.

Alteration of pH of the water and the consequent dissociation of the specific organism from the tubercle.—In a series of laboratory experiments carried out with water having different pH values ranging from 7·0 to 9·2, all the other conditions for tuberculation having been kept the same, it was observed that tuberculation was least with water having pH values between 8·8 to 9·2. Further experiments conducted with the specific organism showed that it cannot flourish in a medium of pH of about 8·8, its optimum pH being between 6·8–7·2.

Since the addition of calcium hydroxide to maintain the pH in the neighbourhood of 9 was not found to impair the quality of water in any manner, it was considered that this method of treatment of water for preventing the formation of tubercles in the cast iron pipes could be applied to the Trivandrum water distribution system.

Application of the above finding to the distribution system.—Pipes in the distribution system were cut out under aseptic conditions, the tubercles in them were scraped off, a further protective coating was applied, and then they were laid out. The addition of calcium hydroxide was well regulated to maintain the pH of the water at about 9·0. Chemical and bacteriological analyses of water have been carried out every day and it has been consistently observed that the quality of the drinking water was not impaired in any way. From time to time, pipes from different parts of the distribution system were also taken out for examination. It was observed on all such occasions that tuberculation was almost negligible.

It may be pointed out that this method of treating the water not only prevents the specific organism from growing in the corrosion products, thereby avoiding tuberculation, but it also prevents corrosion of iron to a great extent. The lime treatment removes carbon dioxide by precipitating bicarbonates as carbonates, supplies a useful material for the formation of a further protective film on the pipe and also increases the pH of water. The dosage of lime should not be excessive—otherwise the water will be caustic and excessive deposits will collect in the pipes—but should be adjusted according to the alkalinity and pH at which corrosion will be least.

Soda ash also increases the pH value of water and may be used to precipitate calcium carbonate in water having a hardness greater than 50 p.p.m. Lime is the best for soft waters, particularly for the one which the author has been dealing with. It is also cheap and available in abundance. The pH value required to reduce corrosion to the minimum may be determined by the marble test.

This method of prevention of tuberculation has been adopted for the last two years and since then no formation of tubercles has been recorded.

Although lime treatment helps to check tuberculation, there are yet certain practical aspects which may require further investigation. Thus, it is not clear as to how much of the extra lime has actually to be present during the preliminary tank treatment. The changes in reaction during storage and

distribution should be followed It is probable that, owing to the presence of dissolved carbon dioxide, the water becomes neutral even after short storage

It will also be of some interest to follow the changes in the iron content of the water The corrosion of the pipe would have been reduced by the addition of extra lime and it may reasonably be expected that the water in the distribution system would contain practically no iron in solution

The present methods of coating the inside of pipes, at any rate in India, seem to be inadequate The protective coat wears off after some time and portions of the bare surface are exposed to the attack of water and the dissolved gases Rusting begins first as scattered pin-points and then spreads rapidly The points of rusting become the nuclei for the formation of tubercles

A more effective method of eliminating tuberculation will be to improve the inner coating of the pipes Superficial coats, however good, are not likely to be permanent. If, on the other hand, the protective material together with some suitable vehicle can be impregnated into the pipes to some reasonable depth, then the protection will be more or less permanent Corrosion will not appear and tuberculation will be prevented effectively

Cast iron pipes are known to be fairly permeable It is possible that some improved system of impregnation can be devised and the pipes thus permanently protected The reaction of the water will then have no influence on the pipes so that no special treatment will then be needed.

VI SUMMARY AND CONCLUSIONS

1 The process of tuberculation begins in the course of about three months after the installation of the pipes for service.

2 Generally, the tubercles are not formed in any order They occur at random, but in the bigger pipes they are practically confined to the two sides, the crown and the invert having very little tuberculation

3 The degree of tuberculation in the different systems may be placed in the following order (i) mains in the distribution system carrying the finally purified water, (ii) pipes containing the treated water, and (iii) those conveying the raw water. The treatment and purification of water seem to accelerate the process of tuberculation

4. The attack of dissolved gases and other corrosive elements takes place where points of bare iron are exposed

5 The present practice of dipping and coating the pipes with the protective material appears to be defective. The desired surface finish is not achieved, so that the necessity of devising improved methods of impregnating the pipes with protective material is stressed

6. The tubercles collected from the particular system are more or less similar in their chemical composition

7 Iron in the ferric condition is the chief constituent, while aluminium, silica, ferrous iron, calcium, magnesium, manganese and phosphorus are

present in much smaller proportions; organic carbon and nitrogen are also present in small quantities.

8. The iron necessary for the formation of the tubercle appears to come mostly from the pipe itself, while the water passing through the pipe system supplies the other constituents. It is more than likely that a large proportion of the silica, phosphorus, manganese and carbon is derived from the pipe, for cast iron contains these in appreciable quantities.

9. There is a slight but apparently progressive increase in the iron content of the water as it passes through the pipe. This would suggest that (*a*) iron from the pipe passes into solution in the water, and (*b*) the iron of the tubercle is not derived exclusively from the water, but mainly from the pipe itself.

10. The tubercles examined contain none of the better known iron bacteria, but they are invariably associated with a lower form of fluorescent bacillus of the *Pseudomonas* type which is derived from the water. The bacterium has been completely characterized and found to be a new species. It has been tentatively named *Pseudomonas ferrugineum*.

11. The most interesting feature about the new species of bacterium is its ability to live and grow in rust.

12. The function of this organism in the formation of tubercles is as follows—it gives to the tubercle the characteristic nodular appearance, the necessary strength and compactness to withstand the current of water thus enabling it to exist indefinitely in the pipe, it also facilitates oxidation of ferrous iron to the ferric condition.

13. This bacterium is not autotrophic; but its reactions with various sugars and a consideration of its morphological and physiological features would indicate that it has not advanced much from its parental form of the strict autotrophic type.

14. Tuberculation is always preceded by corrosion of the principal material of the pipe, namely iron. The dissolved oxygen, carbon dioxide and other corrosive elements, such as chlorine, attack the iron of the pipe, so that the necessary iron for the construction of the tubercle comes almost entirely from the pipe itself.

15. The subsequent transformation of the corrosion products in order to form a tubercle is brought about by a species of bacteria which occurs in almost all waters. Its precise action in the mechanism of tuberculation has been studied and described.

16. The specific organism, probably occupying a comparatively high place in the scale of evolution of iron bacteria, adapts itself to tolerate a large quantity of organic matter contained in its preferential medium of iron oxides.

17. A practical method for preventing the formation of tubercles in the pipe system has been described and recommended.

18. The method has been devised, taking advantage of the specificity of the bacterium found in association with the tubercle and which, to a large

extent, is responsible for the development of the tubercular structure out of the corrosion products. Whereas the organism flourishes best at pH 6.8–7, it finds it difficult to thrive as the pH is raised and finally, it fails to grow when the pH of the medium is about 9.

19. Calcium hydroxide is recommended for maintaining the desired pH. The several advantages of using lime from the bacterial and the hygienic points of view, as also from a consideration of its usefulness in preventing corrosion itself, are described.

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ON THE IONIZATION OF THE UPPER ATMOSPHERE.

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1. INTRODUCTION

There are at present two works attempting a theoretical explanation of the ionization of the Upper Atmosphere First, the work of A Pannekoek (1926), which is thermodynamical, and is based upon Saha's theory of thermal ionization of atoms as extended by Milne (1924) and Woltjer (1925) to material systems traversed by radiation from an external body at a higher temperature. The second method is that of S Chapman (1931*a*, *b*) who considers the ionization produced by the absorption of a monochromatic beam of light in an atmosphere in which the density is assumed to vary exponentially Prof Chapman in a Bakerian lecture in 1931 gave accounts of both theories side by side, but he does not appear to have tried to demonstrate the connection between the two methods of calculating the ionization of the upper atmosphere It will be shown presently that the two theories are not really different, when Chapman's theory is properly developed and extended, it leads to the same result as that of Pannekoek

2. PANNEKOEK'S WORK.

It is necessary to start with a critical description of the main results of these two theories. Pannekoek (1926) shows that the number of electrons produced by the ionization of any one of the constituents in the earth's atmosphere can be obtained from the formula

$$K = \frac{n_+ n_e}{N} = \left(\frac{n_+ n_e}{N}\right)_0 \frac{\displaystyle\int_{\nu_0}^{\infty} \psi(\nu)\ I(\nu)\ d\nu}{\displaystyle\int_{\nu_0}^{\infty} \psi(\nu)\ e^{-\frac{h\nu}{kT}} \left\{\frac{8\pi h\nu^3}{c^2} + I(\nu)\right\} d\nu} \quad \cdots \quad (1)$$

where

$\left(\frac{n_+ n_e}{N}\right)_0 = K_0 =$ Reaction isochore under equilibrium conditions,

$N =$ the number of atoms per unit volume,

$n_+ =$ the number of ions per unit volume,

n_e = the number of electrons per unit volume,
$I(\nu)$ = the intensity of radiation of frequency ν

$\psi(\nu)$ denotes the *probability of ionization* by light of unit intensity $\psi(\nu)$ is connected with the atomic absorption coefficient $\tau(\nu)$ by the relation

$$\psi(\nu) = \tau(\nu)/h\nu$$

There are two things to be noticed about this formula First, that ionization starts at a frequency ν_0 and is produced by radiation of higher frequency just as we know from laboratory experiments Secondly that the values of the density of electrons or of positive ions which we obtain from the above formula are *equilibrium values*, i.e. they are the values of concentration when a condition of equilibrium has been established between the rate of ionization due to solar radiation and the rate of disappearance due to recombination or any other process

3. Chapman's Work

Chapman (1931*a*) shows, following an earlier work by Lenard (1911), that a monochromatic beam of radiation, of intensity $I(\nu)_0$ just outside the earth's atmosphere, is reduced in its passage through the earth's atmosphere at a slanting angle χ, to the intensity $I(\nu)$ given by the formula

$$I(\nu) = I(\nu)_0 \operatorname{Exp}\left\{-A(\nu)\,.\,\rho_0\ H\ \sec\chi\,.\,e^{-\frac{z}{H}}\right\} \quad .. \quad (2)$$

Here $A(\nu)$ is the mass absorption coefficient, and $H = kT/Mg$ is the height of the homogeneous atmosphere The temperature is assumed to be constant Then we have

$$\frac{dI(\nu)}{dz} = I(\nu)_0\ A(\nu)\,.\,\rho_0\,.\sec\chi\,.\operatorname{Exp}\left\{-\frac{z}{H} - A(\nu)\,.\,\rho_0 H\,.\sec\chi\,.\,e^{-\frac{z}{H}}\right\}.$$

It is next supposed that the number of electrons or of positive ions produced is equal to $\beta\ \frac{dI(\nu)}{dz\,.\sec\chi}$ Hence the number of electrons produced per second per unit volume is given by

$$q(\nu) = \beta\,.\,A(\nu)\,.\,I(\nu)_0\ \rho_0\ \operatorname{Exp}\left\{-\frac{z}{H} - A(\nu)\ \rho_0 H\,.\sec\chi\,.\,e^{-\frac{z}{H}}\right\} \quad .. \quad (3)$$

It is easy to see that $\beta = \frac{1}{h\nu}$, but Chapman does not attempt to define β and plots $q(\nu)$ as a function of z and thus gets a curve of variation of density of ions in the earth's atmosphere with height. His theory explains to some extent the variation of electron density of the ionized layers in the course of the day as observed in the radio experiments. Further he shows that the values of maximum electron density in winter and summer are related as

$$\frac{N_e^W}{N_e^S} = \left\{\frac{\sin(\theta-\delta)}{\sin(\theta+\delta)}\right\}^{\frac{1}{2}} \quad . \quad . \quad . \quad (4)$$

where δ is the declination of the sun and θ the colatitude of a place. This relation has been verified approximately by Appleton, Naismith and others (1935)

It should however be mentioned that it is not possible to arrive at an *absolute value* of $q(\nu)$ from Chapman's formula as the constant β is not precisely defined Secondly, Chapman's theory holds only for *monochromatic radiation*, but if we suppose that the sun radiates like a black body, ionization will be produced by continuous radiation in the way supposed by Pannekoek The values which Chapman obtains are not equilibrium values n_e of ionization density, but denote the *number of ions* produced per second by the radiation But what we measure in radio experiments is the *equilibrium value* For unicomponent systems, it can be shown (Appleton, 1938) that $n_e = (q/\alpha)^{\frac{1}{2}}$, but it is hardly correct to say that in the ionosphere we have to deal with a unicomponent system

To show the connection between the two theories, let us first find out the relation between equilibrium value, the rate of production of ions and the rate of recombination Let us take the simplified case of N_2 As a result of reaction with sunlight, we can expect that the N_2 molecule will give rise to the following products —

$$N_2,\ N_2^+,\ N_2^-,\ N,\ N^+,\ N^-,\ e$$

Of these we can exclude the probability of the existence of N_2^- and N^- because, according to a large number of experiments with the mass-spectrograph, the existence of such ions is doubtful (see for example Tüxen, 1936) We can also neglect N and N^+ since, on account of the high dissociation potential of nitrogen, it is rather improbable that there is an appreciable number of free nitrogen atoms and atom-ions present in the atmosphere We are, therefore, left with only N_2, N_2^+ and electrons. Even if some of these assumptions are proved to be incorrect, it does not interfere with the general line of argument followed in the present paper, as we propose here to deal with an idealized state only Further, let us suppose that the ionization of N_2 proceeds in the same way as for the nitrogen atom, i.e the ionization suddenly starts with a sharp maximum at the frequency corresponding to the ionization potential of N_2 and then falls off approximately as $1/\nu^3$ for higher frequencies, although it will be shown in another paper that these assumptions do not strictly hold for the ionization of the molecule

Let us suppose that

$$N,\ n_+,\ n_e$$

are respectively the numbers per c.c. of neutral nitrogen molecules, ionized nitrogen molecules and electrons. We of course for the present assume that $n_+ = n_e$ (unicomponent system) We have then

$$\left.\begin{aligned}\frac{dN}{dt} &= -q+\alpha n_+ n_e = -q+\alpha n_e^2\\ \frac{dn_e}{dt} &= q-\alpha n_+ n_e = q-\alpha n_e^2\end{aligned}\right\} \qquad \ldots \quad \ldots \quad (5)$$

where q is the number of electrons or ions produced by sunlight per c c. and α is the *recombination coefficient.*

When equilibrium has been established, we should have $n_e = (q/\alpha)^{\frac{1}{2}}$. In general, however, electrons arise not merely from the ionization of N_2, but also from O_2, O and probably N, hence the electron-concentration is to be regarded as an independent component. We shall not deal with this matter in this paper, but confine our attention only to calculation of the quantities q and α. We can easily obtain q from an extension of Chapman's method to continuous radiation The number of ions produced by the absorption of radiation of intensity $I(\nu)$ is given by

$$q(\nu)d\nu = \frac{I(\nu)\ A(\nu)\ \rho\ d\nu}{h\nu} = \frac{N\ I(\nu)\ \tau(\nu)\ d\nu}{h\nu} = N\ I(\nu)\,.\,\psi(\nu)\ d\nu \qquad (6)$$

because $I(\nu)\ d\nu\ A(\nu)\ \rho/h\nu$ is the number of quanta absorbed and each quantum produces one ion To prove the relations stated here, we observe that

$A(\nu) =$ mass absorption coefficient $= \tau(\nu)/M$, where $\tau(\nu)$ is the absorption per atom, and M is the mass of the atom.

It will be seen that eq. (6) differs from eq. (3) in having β replaced by $\frac{1}{h\nu}$ Further we have as yet made no suggestion regarding the variation of N or $I(\nu)$ with height.

We have, therefore, for ionization by continuous radiation

$$q = \int_{\nu_0}^{\infty} q(\nu)\,.\,d\nu = N\int_{\nu_0}^{\infty} I(\nu)\,.\,\psi(\nu)\,.\,d\nu \qquad \ldots \quad \ldots \quad \ldots \quad (6')$$

According to Milne (1924), the recombination coefficient is given by

$$\alpha = \int_0^{\infty} 8\pi^2 \left(\frac{m}{2\pi kT}\right)^{3/2} e^{-\frac{1}{2}\frac{mv^2}{kT}} \{F(v)+I(\nu)\ G(v)\}\, v^2\,.\,dv$$

By comparing the results obtained in the case of thermodynamical equilibrium and substituting $\frac{1}{2}mv^2 = h(\nu-\nu_0)$ this transforms into

$$\alpha = e^{\frac{h\nu_0}{kT}}\left(\frac{h^2}{2\pi mkT}\right)^{3/2}\int_{\nu_0}^{\infty} \psi(\nu)\left\{\frac{8\pi h\nu^3}{c^2}+I(\nu)\right\} e^{-\frac{h\nu}{kT}}\,.\,d\nu \quad \ldots \quad (7)$$

Equating the value of $\alpha\, n_+\, n_e$ with q, we have

$$K = K_0 \frac{\displaystyle\int_{\nu_0}^{\alpha} \psi(\nu)\ I(\nu)\ d\nu}{\displaystyle\int_{\nu_0}^{\alpha} \psi(\nu)\ e^{-\frac{h\nu}{kT}} \left\{\frac{8\pi h\nu^3}{c^2} + I(\nu)\right\} d\nu} \qquad (8)$$

because $$K_0 = \left(\frac{2\pi mkT}{h^2}\right)^{-\frac{3}{2}} e^{-\frac{h\nu_0}{kT}}$$

is the value of the reaction-isochore, when radiation is at the same temperature with matter.

This is the original method of deduction by Milne of the equation of reaction-isochore under the conditions stated above It is well known that assuming $\psi(\nu)$ to be given by C/ν^3 and taking $I(\nu)$ in the denominator to be negligible in comparison with $8\pi h\nu^3/c^2$, we arrive at Pannekoek's result, which will be discussed more in detail in section 5. We shall first of all calculate the rate of production of electrons, and the recombination coefficient according to formulæ (6′) and (8). For this purpose it is necessary to know how $\tau(\nu)$ varies with ν This problem is discussed in the next section

4. The Law of Photo-electric Absorption

It is generally assumed (Pannekoek, 1926) that $\tau(\nu)$ varies according to the law first given by Kramers,

$$\tau(\nu) = \frac{16}{3\sqrt{3}} \frac{\pi^2 e^6}{c\, h^3} Z^2 \frac{\nu_0}{\nu^3} \qquad (9)$$

Here 'Z' is the effective charge on the nucleus, ν_0 is the threshold value of absorption frequency. If we wish to apply this formula to photo-ionization of atoms and to molecules like N_2 and O_2, we have to introduce some assumption regarding the effective value of 'Z', which is generally understood to be the nuclear charge minus the 'screening constant' due to the effect of external electrons. Pannekoek (1926) and Chapman (1931) have introduced values for O and N-atoms, and N_2 and O_2-molecules for which their papers may be consulted.

It is, however, doubtful whether Kramers' formula (9) which was first deduced on an older form of the quantum theory to account for X-ray absorption can at all be applicable to optical absorption. Rosseland (1936) comments 'One sometimes has the feeling that the applicability of the formula has been strained beyond the breaking point'

The best course would be to take $\tau(\nu)$ values obtained from actual experiments. But as emphasized by Saha (1937), accurate experiments

have not yet been performed for O_2 and N_2; and for O and N, probably the experiments would be extremely difficult. Under such circumstances, the best course appears to be to fall back upon wave-mechanical considerations.

For the H-atom, it has been shown by several authors [(for a comprehensive account, see Bethe (1932)], that $\tau(\nu)$ is given by

$$\tau(\nu) = \frac{2^8}{3}\ \frac{\pi e^2}{mc} \cdot Z^2\ \frac{\nu_0^3}{\nu^4}\ F\left(\sqrt{\frac{\nu_0}{\nu-\nu_0}}\right) \quad . \quad (10)$$

where $F(x) = \mathrm{Exp}\ \{-4x \cdot \cot^{-1}x\}\ /(1-e^{-2\pi x})$, and for moderate values of $\nu-\nu_0$, we have approximately (ν up to $3\nu_0$)

$$F(\nu) = \frac{\epsilon^{-4}}{3}\left\{\frac{4\nu}{\nu_0}-1\right\} \quad . \quad (10')$$

where ϵ is the base of natural logarithms

We have from (10), and for $Z = 1$

$$\tau_0 = \text{limiting value of } \tau(\nu) \text{ at } \nu = \nu_0$$

$$= \frac{2^8}{3}\ \frac{\pi e^2}{mc}\ \frac{1}{\nu_0}\ \epsilon^{-4} = \frac{2^7}{3}\ \frac{\epsilon^{-4}\ h^3}{\pi e^2 m^2 c} = 1.27 \times 10^{-17}\ cm^2 \quad (11)$$

and $$\tau(\nu) = \frac{\tau_0}{3}\left(\frac{4}{x^3}-\frac{1}{x^4}\right), \text{ where } x = \nu/\nu_0 \quad (12)$$

We have $$\int_{\nu_0}^{\infty} \tau(\nu)\, d\nu = \frac{5}{9}\ \tau_0\ \nu_0 \quad \ldots \quad (13)$$

It will be interesting to compare the value of τ_0 obtained from (11) with that obtained from Kramers' formula For the H-atom, we have $Z = 1$, and

$$\tau_0\ (\text{Kramers}) = \frac{4}{3\sqrt{3}\pi^2}\ \frac{h^3}{e^2\ m^2\ c} = 3.98 \times 10^{-18}\ \text{cm}^2 \quad \ldots \quad (14)$$

$$\tau_0\ (\text{Wave-mechanics}) = \frac{2^5\sqrt{3}\pi}{\epsilon^4} = 3{\cdot}19\ \tau_0\ (\text{Kramers}) \quad \ldots \quad (15)$$

Kramers' value of τ_0 for the H-atom is therefore 3·19 times smaller than the wave mechanical value.

It should, however, be pointed out that the approximation (12) is only rough. This can be seen from a calculation of the oscillator strength for the continuous spectrum of hydrogen. According to a general theorem

$$f_c = \frac{g_i}{g_j} \cdot \frac{mc}{\pi e^2} \int_{\nu_0}^{\infty} \tau(\nu) \cdot d\nu = \frac{g_i}{g_j} \cdot \frac{Z^2\ 2^8}{3}\ \epsilon^{-4} \cdot \frac{5}{9} = 289\ Z^2 \quad . \quad (16)$$

Here

g_i = weight of the normal state of the H-atom ; for H, it is $1s$, $g_i = 2$

g_j = weight of the final state of the H-atom , for H, it is ∞p, $g_j = 6$

The actual value of f_c for H is, however, 43 This discrepancy is due to our use of the approximation (12). The above formula for f_c holds only for the hydrogen-like atoms But in the Upper Atmosphere, it is the following processes which give rise to electrons .

$$O_2 \rightarrow O_2^+, \quad N_2 \rightarrow N_2^+, \quad O \rightarrow O^+, \quad N \rightarrow N^+$$

For calculating the ionization according to each of these processes, we require a knowledge of the corresponding $\tau(\nu)/\nu$-curves It can be assumed that for all atoms, the $\tau(\nu)$ curve is given by a formula of the type (10) or its approximate form (10′) which we use here where Z is to be adjusted In fact, Vinti (1933) has actually deduced theoretically such an expression for the continuous absorption by helium

Molecular Ionization

But a little reflection shows that the same considerations cannot apply to molecules For here ionization is attended usually with a change in the nuclear distance, e g in H_2, the nuclear distance is 75×10^{-8} cm while for H_2^+, it is $1\ 071 \times 10^{-8}$ cm Hence according to the Franck-Condon principle, the value of $\tau(\nu)$ at the threshold potential is likely to be very small as the nuclear distances are very different It will gradually rise to a maximum and then fall off Probably the curve would be similar to that experimentally found by R Ladenburg (1933) for the photo-dissociation of the O_2-molecule by light of wavelength $< \lambda$ 1750A, for Ladenburg's case, a theoretical expression has been found by Stuckelberg (1932) We shall not therefore, in this paper, discuss molecular photo-ionization at all

Ionization of O and N-atoms

This leaves us only with the ionization of the O-atom and the N-atom. It has been surmised by several workers that the O_2-molecule, in the course of the daytime, is completely broken up into atoms Recently a theory of photo-dissociation of molecules has been worked out by Dr R C Majumdar (1938) at the suggestion of the senior author, and making use of Ladenburg's figures for the variation of the absorption-coefficient with ν, he has shown that O_2 in the daytime is completely broken up into atoms at a height of 150 kms

The process $O + h\nu = O^+ + e$ therefore appears to be of great practical value in the production of electrons in the Upper Atmosphere in the daytime

We shall now consider how Z^2 is to be obtained for the O and N-atoms

We proceed from a general theorem by Thomas and Kuhn (see Bethe, *loc cit*, p 434)

$$\Sigma f_i + f_c = n \quad \ldots \quad (17)$$

Where Σf_l is the sum of oscillator-strengths for line radiation, f_c is the oscillator strength for the continuous radiation at the end of the series limit, the initial state being the normal state of the atom, 'n' is the number of equivalent electrons which can perform the transition in question. In the case of the O-atom, the photo-ionization can be represented symbolically as

$$1s^2\,2s^2\;\;2p^4 \rightarrow 1s^2\,.\,2s^2\;\;2p^3\left.\begin{matrix}\infty\, s\\ \infty\, d\end{matrix}\right\}$$

to find out f_c, we have to find out Σf_l, for

$$2p^4 \rightarrow 2p^3(ms,\ md)$$

transitions and over all values of m from $m = 3$ to $m =$ infinity.

This problem is difficult to solve, but it appears unlikely that Σf_l can be greater than unity. We can therefore put $f_c = 3$ for the O-atom, and 2 for the N-atom approximately This view is consistent with that of Herzfeld and Wolf (1925) who showed, from a discussion of the dispersion curves of Ne, A and other rare gases, that for a proper interpretation of the course of dispersion of these gases, we have to suppose that the characteristic frequency in the Lorentz-expression for dispersion is not given by the resonance line of the element, but by a line which lies in the region of continuous absorption by the atom and that the number of equivalent electrons per atom for inert gases is nearly 5. In other words, when we have a large number of equivalent electrons in any shell, the tendency for ionization proportionately rises. We assume that when an atom contains r equivalent electrons in the outermost shells, $f_c = r-1$ approx. provided r is large compared to unity. For helium, which contains two equivalent electrons, Vinti (1933) finds that $f_c = 1\ 52$.

Z is now obtained from the formula for oscillator-strength

$$f_c = \frac{g_i}{g_j}\,\frac{mc}{\pi e^2}\int_{\nu_0}^{\infty}\tau(\nu)\,.\,d\nu. \qquad \ldots \qquad \ldots \qquad \ldots \quad (18)$$

Substituting for $\tau(\nu)$ the value in (12),

$$f_c = \frac{g_i}{g_j}\,(\ 867)Z^2$$

But there are further complications in the present cases. The normal oxygen atom has the electronic constitution $1s^2\ 2s^2\ 2p^4\ ({}^3P_{210}\ {}^1D_2\ {}^1S_0)$, and the oxygen-ion has the constitution $1s^2\ 2s^2.\ 2p^3\ ({}^4S_{3/2}\ {}^2D,\ {}^2P)$ The transitions contemplated, which cause ionization, can take place from any state of the normal O-atom to that of any normal O-ion provided this is permissible, and in the calculation of f_c, all such separate transitions must be taken into account.

The continuous transitions fall into the following groups .—

$$\left.\begin{array}{l} O\,{}^3P \to O^+\,({}^4S)_{sd} \\ \quad \to O^+\,({}^2D)_{sd} \\ \quad \to O^+\,({}^2P)_{sd} \end{array}\right\} \begin{array}{lll} f_{c_1} & I\,P. & 13\ 55 \text{ volts} \\ f_{c_2} & & 15\ 86 \ \ldots \\ f_{c_3} & & 18\ 54 \ \ldots \end{array}$$

$$O\,{}^1D_2 \to O^+\,({}^2D)_{sd} \;.\; f_{c_4} \ldots\ldots$$

$$O^+\,({}^2P)_{sd} \;.\; f_{c_5} \ldots$$

$$O\,{}^1S_0 \to O^+\,({}^2P)_{sd} \ldots f_{c_6}$$

The symbols (sd) denote that the hyperbolic orbit of the electron, which is released, may have $l = 0$, or 2 This is necessary for calculation of the weight factors We therefore expect (neglecting the small fine structure due to the presence of three ${}^3P$-states) that there will be six distinct continuous absorption curves corresponding to the six processes mentioned above In fact, we have

$$f_c = 3 = f_{c_1} + f_{c_2} + \ldots \ldots f_{c_6}$$

To calculate the relative values of the quantities f_{cr}, we can apply the arguments of Menzel and Goldberg (1936) about the parentages of the terms of the l^k-shell According to these authors :—

$$\frac{f_{c_1} + f_{c_2} + f_{c_3}}{9(= g \text{ of } {}^3P)} = \frac{f_{c_4} + f_{c_5}}{5(= g \text{ of } {}^1D_2)} = \frac{f_{c_6}}{1(= g \text{ of } {}^1S_0)} = \frac{3}{15}$$

and $$f_{c_1} : f_{c_2} : f_{c_3} = 4 : 10 : 6$$

Hence $f_{c_1} = \frac{9}{25}$, $f_{c_2} = \frac{9}{10}$, $f_{c_3} = \frac{27}{50}$.

We have therefore from (16) for the process $O\,{}^3P \to O^+\,{}^4S$

$$Z^2 = \frac{g_j}{g_i} \frac{f_{c_1}}{867} = \frac{48}{9} \frac{9}{25 \times 867} \quad \ldots \quad \ldots \tag{19}$$

because

$$g_i = \text{weight factor of } O\,{}^3P_{210} = 9$$

$$g_j = \text{weight factor of } (O^+\,{}^4S)_{sd} = 48$$

we get $Z = 1\ 49$.

The value of τ_0 for the process $O\,{}^3P \to O^+\,{}^4S$ now becomes

$$\tau_0 = \frac{2^8}{3} \frac{\pi e^2}{mc} \cdot \frac{1}{\nu_0} \epsilon^{-4} Z^2 = 2\ 81 \times 10^{-17} \cdot cm^2$$

The value given by Chapman is $2{\cdot}5 \times 10^{-16}\ cm^2$, i e. nearly nine times larger.

We can, in a similar way, find out the effective values of Z for the processes

$$O\,{}^3P \rightarrow O^+\,({}^2D)_{sd},\ O\,{}^3P \rightarrow O^+\,({}^2P)_{sd}.$$

The g_j-value of $(O^+\,{}^2D)_{sd}$ state is 120, and that for $(O^+\,{}^2P)_{sd}$ is 72. The corresponding Z-values are 3 04 and 2·36 respectively

There will certainly be some difficulty in following why the effective nuclear charge in O should be different for the three processes mentioned above But actually there is no difficulty as can be seen from the argument that $\tau(\nu)$ is given by the value of the transition-probability, from a certain initial (lower) state to a final state Hence it will involve the effective nuclear charge for the initial as well as the final state In fact, Z^2 should be replaced by $Z_i\,Z_f$. In these cases, though Z_i is identical, Z_f is different, as the electrons of the ion have different configurations, when giving rise to the different terms Further, as it is a question of transition-probability, Z^2 may be widely different

We have not calculated Z-values for transition from $O\,{}^1DS$ to $O^+\,{}^2DP$-states, as probably there are not sufficient $O\,{}^1DS$-atoms in the ionosphere capable of producing any sensible ionization, for $O\,{}^1DS$-atoms produced by any photo-electric process almost instantaneously revert to $O\,{}^3P$-state.

The Nitrogen-atom

These considerations may now be extended also to the nitrogen-atom We have now

$$f_c = 2.$$

The f_c-value is distributed as follows —

$$\begin{array}{lll}
N\,2p^3\ {}^4S \rightarrow N^+\,2p^2({}^3P)_{sd} & f_{c_1} \;..\; I\,P & .\ 14\ \ 46 \text{ volts.} \\
\quad {}^2D \rightarrow N^+\,(2p^2\ {}^3P)_{sd} & ..\,f_{c_2} & . \\
\quad\quad N^+\,(2p^2\,.\,{}^1D_2)_{sd} \ldots & f_{c_3} & \ldots \\
\quad {}^2P \rightarrow N^+\,(2p^2\,.\,{}^3P)_{sd} & .\,f_{c_4}\,.. & \\
\quad\quad N^+\,(2p^2\ {}^1D_2)_{sd}\,. & f_{c_5}\ . & . \\
\quad\quad N^+\,(2p^2\ {}^1S_0)_{sd}\ ..\ . & f_{c_6} & \ldots
\end{array}$$

We have

$$\frac{f_{c_1}}{4} = \frac{f_{c_2}+f_{c_3}}{10} = \frac{f_{c_4}+f_{c_5}+f_{c_6}}{6} = \frac{f_c}{20}$$

and $$f_{c_2} \cdot f_{c_3} = 9\ \ 5\ ,\ f_{c_4}\ \ f_{c_5} \cdot f_{c_6} = 9\ \ 5 : 1.$$

Hence we have

$$f_{c_1} = 4,\ Z = 3{\cdot}53.$$

We need not calculate the Z-values for the other states of nitrogen, as practically all N-atoms will be in the ${}^4S$-state.

5. Rate of Production of Electrons by Photo-ionization

We shall now use the expression for $\tau(\nu)$ in formula (10) for the calculation of q according to the expression (6). We observe that if p be the partial pressure due to the absorbing particles at the region considered

$$I(\nu) = I(\nu)_0 \text{ Exp}\left\{ -\frac{p\,\tau(\nu)}{Mg} \sec\chi \right\} \qquad (20)$$

when radiation is incident at an angle χ to the vertical, and $I(\nu)_0$ is the intensity of light just outside the earth's atmosphere. The relation (20) is proved as follows (first given by Pannekoek, 1926). On passing through a layer having the thickness dz (the layers are supposed to be parallel), the diminution in intensity is given by

$$dI(\nu) = -I(\nu)\ N\,\tau(\nu)\ dz\ \sec\chi \quad .. \qquad (21)$$

We have further the hydrostatic equation

$$dp = NgM\,dz,\ \text{i.e.},\ Ndz = dp/gM \quad .. \qquad (22)$$

Here M is the mass of each particle, and p is reckoned from the top of the atmosphere.

From (21) and (22) we have

$$\frac{dI(\nu)}{I(\nu)} = -\frac{\tau(\nu)}{gM}\,dp\,\sec\chi,$$

and on integrating this, we arrive at expression (20). It is easy to verify that for an isothermal layer, (20) reduces to (2), but (20) is more general. Substituting this in (6')

$$q = N\,.\int_{\nu_0}^{\infty} I(\nu)_0\ \psi(\nu)\ \text{Exp}\left\{ -\frac{p\,\tau(\nu)}{Mg}\ \sec\chi \right\} d\nu \qquad (23)$$

It is found rather difficult to integrate (23) rigorously on account of complexity of its form.

We can replace $\tau(\nu)$ within the integral (23) in the exponential by its mean value $\frac{5}{9}\tau_0$, where τ_0 is the value of $\tau(\nu)$ at the threshold frequency. We have then, taking the exponential term outside,

$$q = \frac{p}{kT}\text{ Exp}\left\{ -\frac{5}{9}\ \frac{p\tau_0}{Mg}\ \sec\chi \right\} \int_{\nu_0}^{\infty} I(\nu)_0\,\psi(\nu)\ d\nu$$

Now as we have

$$I(\nu)_0 = \frac{8\pi\beta\ h\nu^3}{c^2}\,e^{-\frac{h\nu}{kT_s}}\ ,\ \psi(\nu) = \tau(\nu)/h\nu$$

where $4\pi\beta$ is the solid angle subtended by the sun at the earth, $\beta = \frac{1}{230,000}$, T_s = temperature of the sun. The integral reduces to

$$\frac{8\pi\beta}{c^2}\int_{\nu_0}^{\infty} \nu^3 e^{-\frac{h\nu}{kT_s}} \tau(\nu)\ d\nu.$$

For $\tau(\nu)$, we can write the approximate value (12)
Hence the integral

$$= \frac{8\pi\beta}{c^2} \cdot \frac{\tau_0}{3} \nu_0^3 \int_1^{\infty} \left(\frac{4}{x} - \frac{1}{x^2}\right) e^{-\mu_1 x} \, . \, dx$$

where $\mu_1 = \frac{h\nu_0}{kT_s}$. If we put $T_s = 6240°\text{K}$ and ν_0 = ionization threshold frequency for the oxygen atom, it can be easily seen that $\mu_1 = 25{\cdot}78$ and for such large values of the index, it is easy to show that

$$\int_1^{\infty} \left(\frac{4}{x} - \frac{1}{x^2}\right) e^{-\mu_1 x} \, . \, dx = \frac{3e^{-\mu_1}}{\mu_1}.$$

Hence we have

$$q = \frac{8\pi\beta}{c^2 h} \cdot \tau_0 \cdot \nu_0^2\ T_s\ e^{-\frac{h\nu_0}{kT_s}} \cdot \frac{p}{T} \cdot \text{Exp}\left\{ -\frac{5}{9}\frac{p\,\tau_0}{Mg} \sec\chi \right\}$$

$$= A \cdot \frac{p}{T} \cdot \text{Exp}\left\{ -\frac{p \, . \sec\chi}{p_0} \right\} \qquad \ldots \qquad (24)$$

where

$$\left.\begin{aligned} A &= \frac{8\pi\beta}{c^2 h} \tau_0 \nu_0^2 T_s\ e^{-\frac{h\nu_0}{kT_s}} \\ p_0 &= \frac{9}{5}\ \frac{Mg}{\tau_0} \end{aligned}\right\} \qquad \ldots \qquad (25)$$

We can now try to find out the maximum value of q.
Differentiating (24), we have

$$\frac{1}{q} \cdot \frac{dq}{dz} = \frac{dp}{dz}\left(\frac{1}{p} - \frac{\sec\chi}{p_0}\right) - \frac{1}{T}\frac{dT}{dz} \ldots\ldots$$

Let us first assume that $\frac{dT}{dz} = 0$, though we cannot be sure of the truth of this assumption. We have then

$$\frac{dq}{dz} = 0, \text{ when } p = \frac{9}{5}\frac{Mg}{\tau_0} \Big/ \sec\chi = p_0 \cos\chi \quad \ldots \quad \ldots \quad (26)$$

p_0 is the partial pressure at the place where we have maximum production of ions under vertical incidence For incidence at an angle χ to the vertical, the maximum concentration is reached at the pressure $p = p_0 \cos \chi$.

Inserting this value of p in (24), we have for q_m, the maximum production of ions at angle χ, the expression

$$q_m = q_0 \cos \chi \qquad . \qquad . \quad (27)$$

where q_0 = maximum production of the ions under vertical incidence, and it is given by

$$q_0 = \frac{A}{T} \cdot \frac{9}{5} \cdot \frac{Mg}{\epsilon \tau_0} = \frac{8\pi\beta}{c^2 h} \cdot \frac{9}{5} \cdot \frac{Mg}{\epsilon} \frac{T_s}{T} \nu_0^2 e^{-\frac{h\nu_0}{kT_s}} \qquad . \quad (28)$$

We observe that q_0 is independent of τ_0 This is because the smaller is the value of τ_0, the higher is the partial pressure where maximum ionisation is reached

The value of q, at a point where the pressure is p, is given by

$$q = q_0 y \operatorname{Exp}\{1 - y \sec \chi\} \qquad . \qquad (29)$$

where $y = p/p_0$

It can be easily shown that (29) yields us Chapman's expression for electron-production, if p is supposed to be given by the isothermal law

$$p = P \operatorname{Exp}\left\{-\frac{h}{H}\right\}$$

where $H = \frac{kT}{Mg}$ = height of the homogeneous atmosphere, P = ground pressure.

For we can put, following Chapman,

$$p_0 = P . \operatorname{Exp}\{-h_0/H\} \quad z = (h - h_0)/H$$

so that $y = p/p_0 = e^{-z}$

Then (29) becomes

$$q = q_0 \operatorname{Exp}\{1 - z - e^{-z} . \sec \chi\} \quad . \quad .. \quad . \quad (30)$$

This is the expression given by Chapman for variation of production of ions with height.

We have thus proved that even when photo-ionization is produced by continuous light, variation of ion-production with height continues to be given by Chapman's formula when T is supposed to be constant. Chapman proved the correctness of (30) for monochromatic light only. Further, *and this is a definite advance on Chapman's result*, we have now a perfectly definite expression for q_0 which is left undefined in Chapman's method of deduction.

We can now try to give some numerical calculations for q_0 and p_0 for the oxygen atom. As shown before, we have for the process

$$O\,^3P \rightarrow O^+\,^4S, \quad Z = 1{\cdot}49, \quad \nu_0 = 109837\, c.$$

Substituting these values in (25), we obtain

$$A = 3{\cdot}71\times10^{8}, \quad p_0 = \frac{9}{5}\,\frac{Mg}{\tau_0} = 1{\cdot}65\times10^{-3} \text{ dynes}$$

$$q_0 = \frac{1{\cdot}35\times10^{5}}{T} \qquad \ldots \qquad (31)$$

We have assumed that $T_s = 6240^0$K.

Appleton (1938) has calculated from the maximum electron-concentration curve that at Slough for an equinoctial day, when $\chi = 52°$, $q_m = 78$, and for a midsummer day, i.e. for $\chi = 29°$, $q_m = 88$. These values may be compared with those available from (31).

We have

$$q = q_0 \cos\chi = \frac{1{\cdot}35\times10^{5}\cos\chi}{T}$$

$$= 8{\cdot}3\times10^{4}/T \quad \ldots \text{ for equinoctial noon}$$

$$= 11{\cdot}8\times10^{4}/T \quad \ldots \text{ for midsummer noon}$$

If we take T, the temperature for the F_2-layer at noon 1065°K, for an equinoctial day, and 1350°K for a midsummer day, the above results are explained. These values are not inconsistent with the values now assigned to the temperature of the Upper Atmosphere (Appleton, 1935).

We have given these results with a certain amount of reserve; it must not be supposed that we commit ourselves to the opinion that the F_2-layer is due solely to the ionization of O-atoms. We merely wish to point out that our calculations give us the right order of result.

Formula (7) gives us the recombination coefficient α. We can now neglect $I(\nu)$ in comparison to $8\pi h\nu^3/c^2$, and put for $\tau(\nu)$ the expression (12). We obtain after some work, for recombination between $O^+\,{}^4S$ and e,

$$\alpha = \frac{h}{(2\pi m)^{3/2}k^{\frac{1}{2}}}\;\frac{8\pi}{c^2}\;\tau_0\,\nu_0^{2}\;\frac{1}{T^{\frac{1}{2}}} \qquad (32)$$

when we introduce the values of τ_0, ν_0, for the process

$$O^+\,{}^4S + e = O\,{}^3P, \quad \alpha = \frac{1{\cdot}25\times10^{-10}}{T^{\frac{1}{2}}} = 6{\cdot}3\times10^{-12}$$

provided $T = 400°$K. This value may be compared with the figures given by Appleton (1938), whose average values are nearly 10–20 times larger.

6. Equilibrium Value of Electron Concentration

The equilibrium value of electron concentration can now be easily calculated by putting for $\tau(\nu)$ the expression (12), in formula (8). We have now

$$K = K_0 \frac{\beta \int_1^\infty \left(\frac{4}{x} - \frac{1}{x^3}\right) e^{-\mu_1 x} \operatorname{Exp}\left\{ -\frac{p\tau_0}{3Mg}\left(\frac{4}{x^3} - \frac{1}{x^4}\right) \sec\chi \right\}}{\int_1^\infty \left(\frac{4}{x} - \frac{1}{x^3}\right) e^{-\mu_2 x}\, dx}$$

where $\mu_1 = \frac{h\nu_0}{kT_s}$, $\mu_2 = \frac{h\nu_0}{kT}$, $x = \nu/\nu_0$

Now both μ_1 and μ_2 are large quantities In fact, as we have seen, if we take $T_s = 6240°K$, $\mu_1 = 26{\cdot}9$, and for $T = 1000°K$, $\mu_2 = 161\ 4$

The quantity

$$\operatorname{Exp}\left\{ -\frac{p\tau_0}{3Mg} \sec\chi \left(\frac{4}{x^3} - \frac{1}{x^4}\right)\right\}$$

within the upper integral can be replaced by its mean value

$$\operatorname{Exp}\left(-\frac{5}{9}\frac{p\tau}{Mg} \sec\chi\right),$$

and taken outside as already described

We can then easily show that

$$K = K_0 \beta . \frac{\mu_2}{\mu_1} e^{-(\mu_1 - \mu_2)} \operatorname{Exp}\left\{ -\frac{5}{9}\frac{p\tau_0}{Mg} \sec\chi \right\}$$

$$= \beta T_s T^{\frac{1}{2}} e^{-\frac{h\nu_0}{kT_s}} \left(\frac{2\pi mk}{h^2}\right)^{3/2} \operatorname{Exp}\left\{ -\frac{5}{9}\frac{p\tau_0}{Mg} \sec\chi \right\} \quad . \qquad (33)$$

which has the same form as the result deduced by Pannekoek We have the factor 5/9 instead of Pannekoek's $\frac{2}{3}$. From this expression, we can easily calculate the maximum equilibrium value of electron concentration We have according to (1)

$$K = \frac{n_+ n_e}{N} = \frac{q}{\alpha N}$$

and the last relation can be easily verified by reference to formulæ (24) and (32) for q and α. If $n_+ = n_e$, as will happen in the case of unicomponent systems, we have $n_e = (q/\alpha)^{\frac{1}{2}}$. From this, it is clear, as α involves T only, and is independent of p, that in an isothermal atmosphere, the maximum value of n_e will occur at the same place as that for q. It is now easy to show that

$$\left.\begin{aligned} n_0 &= (q/\alpha)^{\frac{1}{2}} = \frac{2\ 55 \times 10^7}{T^{1/4}} \\ n_m &= n_0(\cos\chi)^{\frac{1}{2}} \\ n_e &= n_m y^{\frac{1}{2}} \operatorname{Exp} \tfrac{1}{2}\{1 - y \sec\chi\} \\ \text{where } y &= p/p_0 \end{aligned}\right\} \qquad (34)$$

The variation of electron-density in the E and F_1-layer is found to be given by the law $n = n_0(\cos x)^{\frac{1}{2}}$ during hours of daylight. This is often cited (see Appleton, 1938) as proof of the correctness of Chapman's theory of simple region formation. But formulæ (30) and (35) show that this relation holds good even when electrons are produced by continuous light

7 Ionization by Monochromatic Light

In this section, we shall give a treatment of the ionization produced by monochromatic light, because it has been pointed out by several investigators that many upper air phenomena are probably due to ionization by monochromatic light from the sun Maris and Hulburt (1929) talks of flares of ultraviolet radiation to account for magnetic storms, and abnormal display of aurora One of us (Saha, 1935) has pointed out that the strong N_2^+-ionization observed by Slipher (1933), in the morning and evening flash of sunlight in the Upper Atmosphere, is due to photo-ionization of N_2 due to emission lines of $He\ 1s^2\ {}^1S_0 - 1smp\ {}^1P$. Dellinger (1937) and others have tried to connect the sudden bursts of ionization which give rise to radio fade-outs in the sunlit part of the globe to the occurrence of disturbed regions on the sun showing strong H_α and H_β-lines in emission (vide further a note by R. N Rai and K. B Mathur, 1937).

The number of electrons produced by a monochromatic beam of intensity $I(\nu)$ is given by

$$q = N \quad I(\nu) \,.\, \psi(\nu) \,.\, \Delta\nu.$$

Here $\Delta\nu$ is the equivalent breadth, N is the number of atoms or molecules in the region. Then we have

$$\text{since } I(\nu) = I(\nu)_0 \operatorname{Exp}\left\{ -\frac{p\ \tau(\nu)}{Mg} \,.\, \sec\chi \right\}$$

$$\text{and } \quad N = p/kT$$

$$q = A'\frac{p}{T} \operatorname{Exp}\left\{ -\frac{p\ \tau(\nu)}{Mg} \ \sec\chi \right\}$$

$$\text{where } \quad A' = \frac{I(\nu)_0\ \psi(\nu)\ \ \Delta\nu}{k}$$

This expression is exactly similar to the expression (30) for ion-production by continuous light, but is considerably simpler. Here

$$A' = \frac{I(\nu)_0\ \Delta\nu\ \tau(\nu)}{k\ \ h\nu}$$

is proportional to number of quanta absorbed per atom, and $\tau(\nu)$ has a perfectly definite value. The value of $I(\nu)_0$ depends upon the intensity of the light which may be available from astrophysical measurements, and the dimensions of the disturbed area on the sun. In case the disturbance extends over the

whole surface, $I(\nu)_0$ is proportional to β but otherwise it will be much less, and will be equal to the solid angle subtended by the disturbed region in the earth's atmosphere.

We can find out q, q_m, q_0 as defined in sec 5 exactly in the same way as there, and we have for an isothermal atmosphere

$$\left.\begin{aligned} q_m &= q_0 \cos\chi \\ q_0 &= \frac{A'}{T}\frac{gM}{\epsilon\tau(\nu)} = \frac{I(\nu)_0\,\Delta\nu}{h\nu}\frac{gM}{\epsilon kT} \\ q &= q_0 y \operatorname{Exp}\{1-y\sec\chi\} \\ y &= p/p_0,\ \text{where } p_0 = \frac{gM}{\epsilon\,\tau(\nu)} \end{aligned}\right\} \tag{35}$$

Attention may be drawn to the expression for q_0, the maximum electron-production per c c under vertical incidence—it is equal to the total number of ions produced by the total absorption of the beam divided by ϵH, where H is the height of the homogeneous atmosphere This relation is identical with that obtained by Lenard and Chapman

ABSTRACT

It has been shown that the two theories of upper air ionization, viz that of Pannekoek and Chapman, are not essentially different from each other When in the Chapman theory we give to the quantity β, which is introduced as a proportionality factor for deducing the number of electrons from the radiation absorbed, the value $\frac{1}{h\nu}$, and extend it to continuous radiation, we come to Pannekoek's results. For absorption coefficient $\tau(\nu)$, a wave mechanical formula is used in the place of the Kramers-expression. Rates of production of electrons from the O-atoms, the recombination coefficient of ions and electrons, and equilibrium values of electron concentration are deduced for unicomponent systems. From these expressions, Chapman's formulæ for variation of electron-production with height is deduced as a special case but the scope of the formula is found to be greater as it is found to hold not only for monochromatic light, as in Chapman's, but also for continuous light. Actual values of electron production at noon for the F-layer from the O-atom are given, and compared with figures given by Appleton

It is further shown that the method is capable of giving also formula for electron production by monochromatic light, and yields results in terms of quantities which are physically definable

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Note.—This paper was read before the Silver Jubilee session of the Indian Science Congress in January, 1938, but for unavoidable reasons it could not be sent for publication before April While correcting the final proof it was brought to our notice by Dr R C Majumdar that a paper had been published by E O Hulburt in *Phys Rev*, March, 1938, in which some of the results deduced in this paper have been obtained by a somewhat different procedure —(*M N S*, 15th July, 1938)

LEVI-CIVITA'S FORMULÆ FOR TWO BODIES

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(*Read August 20, 1938.*)

1 It was shown in *Proc. Acad Sci India*, Vol 4, pp 20–23 (August 1934), that extra terms, in the equation of motion, as compared to Newton's, can be treated as being due to small perturbing forces and the changes in the elements of the orbit deduced by ordinary Dynamics In *Proc Nat Acad Sci India*, Vol. 6, p. 280 (August 1936), the acceleration of one body relative to another body of comparable mass as well as its acceleration for actual motion in space were given

For relative motion the potential function is

$$V = \frac{G(M+m)}{r} + \frac{G(M+m)h^2}{c^2} \cdot \frac{1}{r^3}$$

where r is the distance between the two bodies, M and m their masses, G the gravitational constant, h double the areal rate and c the velocity of light. This correctly yields the differential equation

$$\frac{d^2u}{d\theta^2} + u = \frac{\mu}{h^2} + \frac{3\mu}{c^2} \quad u^2$$

2 Prof Tullio Levi-Civita in the *American Journal of Mathematics* (Vol LIX, No 2, April 1937, pp 225–234) has also treated the extra effect as 'first order perturbations', and following Newtonian principles deduced certain Astronomical consequences of Relativistic Two-Body Problem

He has found that for two bodies of comparable masses, the trajectory may be considered to be that of a central force with the potential function for relative motion (in our notations) as

$$V = \frac{G(M+m)}{r} + 3\left\{1 - \frac{1}{2}\,\frac{Mm}{(M+m)^2}\right\}\frac{G^2(M+m)^2}{c^2 \quad r^2}$$
$$+ \frac{1}{2}\,\frac{Mm}{(M+m)^2} \cdot \frac{c^2h^2}{G^2(M+m)^2} \cdot \frac{G^3(M+m)^3}{c^4 \,.\, r^3}$$

He has then concluded that the first term represents the Newtonian attraction, and the other two (both of the second order) are the relativistic perturbations varying according to the inverse cube and the inverse fourth power respectively of the distance, and has then inferred that by putting one of the masses equal to zero we get

$$3\,\frac{G^2M^2}{c^2r^2}$$

for the perturbative function of the Einstenian one-centre problem (*loc. cit.*, p 229) The angular precession (per revolution) of the periastron in the case of a double star turns out to be the same as the precision for an infinitesimal

planet moving about a central mass possessing the total mass of the binary system

$$\Delta \bar{\omega} = \frac{6\pi G^2(M+m)^2}{c^2h^2}.$$

3. (i) It can however be pointed out that the extra terms do not strictly represent the Einstenian perturbation.

For an infinitesimal planet we put $m = 0$, and obtain from the above potential function the acceleration by differentiation as

$$f = -\frac{GM}{r^2} - \frac{6G^2M^2}{c^2r^3} \text{ only}$$

which is

$$= \frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2$$

Substituting $r = \frac{1}{u}$ and therefore

$$\frac{d^2r}{dt^2} = -h^2u^2\,\frac{d^2u}{d\theta^2}$$

while for planets $r^2\frac{d\theta}{dt} = h$ fairly approximately, we get

$$-h^2u^2\left[\frac{d^2u}{d\theta^2}+u\right] = -GMu^2 - \frac{6G^2M^2}{c^2}\,u^3$$

or

$$\frac{d^2u}{d\theta^2}+u = \frac{GM}{h^2}+\frac{6G^2M^2}{c^2h^2}\cdot u.$$

This is not at all identical with Einstein's equation in which the last term contains u^2 and not u.

Putting $\sqrt{1-\frac{6G^2M^2}{c^2h^2}} = k$, $kh = h'$ and $k\theta = \theta'$, the equation becomes

$$\frac{d^2u}{d\theta'^2}+u = \frac{GM}{h'^2},$$

which has the Newtonian and not the Einstenian form, and for which the solution is

$$u = \frac{GM}{h'^2}+A\cos(\theta'+B),$$

where A and B are constants. This is a complete ellipse revolving round the centre of force in a forward direction, which was known to Newton.

(ii) Indeed this law of gravitation can be obtained without Levi-Civita's elaborate method and directly from Eddington's *supposed* solution of Einstein's orbital equation as given in his Relativity (p. 88)

$$u = \frac{\mu}{h^2}\left[1+e\cos\left(1-\frac{3\mu^2}{h^2c^2}\right)\theta\right].$$

Treating $\left(1-\frac{3\mu^2}{h^2c^2}\right)\theta$ as a new variable, this is obviously the solution of

$$\frac{d^2u}{\left(1-\frac{3\mu^2}{h^2c^2}\right)^2 d\theta^2}+u=\frac{\mu}{h^2}.$$

Hence $\frac{d^2u}{d\theta^2}+u=\frac{\mu}{h^2}+\frac{6\mu^2}{c^2h^2}$ u, nearly

Eddington's solution suffers exactly from the same defect as Levi-Civita's, being really the solution of another differential equation

4 Levi-Civita's potential function cannot yield any value for the spectral shift of light And even the value for the deflection of light from stars obtained from Levi-Civita's formula does not tally with Einstein's value

(i) Taking R as the perpendicular distance from the centre of the Sun on an asymptote and ψ the angle between this perpendicular and the radius vector, the deflection

$$\epsilon=\frac{1}{c^2R}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\left[-\frac{GM}{r^2}-\frac{6G^2M^2}{c^2r^3}\right]r^2\cos\psi\, d\psi \quad \text{where } r\cos\psi=R$$

$$=-\frac{GM}{c^2R}\left[2+\frac{3\pi GM}{c^2R}\right]$$

$$=\frac{2GM}{c^2R}\text{, nearly,}$$

which is equal to Newtonian value very nearly, and not at all to Einstein's.

(ii) The value of the advance of perihelion, however, comes out correct

$$\Delta\,\bar{\omega}=-\int_0^{2\pi}\frac{6G^2M^2}{c^2r^3}\;\frac{\cos\theta}{e}\sqrt{\frac{a(1-e^2)}{\mu}}\,dt$$

where $r^2\frac{d\theta}{dt}=h$ nearly, and $\frac{1}{r}=\frac{\mu}{h^2}(1+e\cos\theta)$ nearly

$$=\frac{6\pi G^2M^2}{c^2h^2}.$$

(iii) The spectral shift of light from the edge of the Sun treated as depending on the difference of potential is given by

$$\frac{\lambda_s}{\lambda_e}=1+\frac{GM}{a}\left(1+\frac{3GM}{c^2a}\right)\text{ nearly}$$

$$=1+\frac{GM}{a}$$, nearly, where a is the radius of the Sun.

Hence the shift remains the same as that of light from the centre.

(iv) If we proceed to a higher approximation and take

$$r^2 \frac{d\theta}{dt} = h\left(1 - \frac{2GM}{c^2 r}\right),$$

even the value for the advance of perihelion is upset In the differential equation the second biggest term will still contain u

5 Discarding Relativity concepts, Levi-Civita has also considered the *absolute* motion in the sky of a double star system. His conclusions are·—

(i) The acceleration of the centre of mass G of a double star lies entirely in the plane of (relative) orbit and the common plane of (absolute) orbits

(ii) The secular acceleration of the centre of mass G of the double star is directed along the major axis towards the periastron of the principal star.

(iii) Taking the origin at the centre of the principal star and measuring α towards the periastron of the (undisturbed) elliptical orbit of the other star, and taking the component of the ordinary velocity of G as $c\alpha_1$, and denoting by $c\bar{\alpha}_1$ its secular part in terms of θ, he gets—

$$c\bar{\alpha}_1 = -\frac{1}{2}\frac{Mm}{(M+m)^2}\frac{M-m}{(M+m)}\cdot\frac{e}{(1-e^2)^{\frac{3}{2}}}\quad\frac{G(M+m)}{c^2}\sqrt{\frac{G(M+m)}{a^3}}\,\theta.$$

He has pointed out that a difference of velocity along the apsidal line, having a component also in the line of sight, ought to be detectable eventually by spectroscopic observation of binaries for which photometric observations also are available

6. If there were a net acceleration of the centre of gravity, then (1) it must obviously be in the common plane of the two orbits, and (2) as the principal star has a larger mass and is therefore nearer the centre of gravity, and nearest at the periastron, it is equally obvious that the residue of the acceleration would be directed along the major axis towards the periastron But on the principle of the equality of action and reaction, there cannot be any acceleration of the centre of gravity without extraneous influences.

According to the second paper mentioned in para. 1 the respective forces in absolute space round their common centre of gravity 0 taking the masses as being concentrated at their centres are

$$-\frac{GM^3}{(M+m)^2}\frac{m}{OP^2}-\frac{3GM^5h^2}{c^2(M+m)^4}\cdot\frac{m}{OP^4}$$

and

$$+\frac{GM^3}{(M+m)^2}\cdot\frac{M}{Op^2}+\frac{3Gm^5h^2}{c^2(M+m)^4}\cdot\frac{M}{Op^4}$$

which are equal and opposite, as $M\,Op = m\,OP$, and therefore cancel each other

There can therefore in such a case be no net acceleration at all.

THE VARIATION OF SOUND ABSORPTION COEFFICIENT WITH INTENSITY.

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(Read January 5, 1937)

(Communicated by Prof M. N SAHA, D Sc , F R S)

Section 1. INTRODUCTION.

The variation of sound-absorption coefficient with intensity of sound has never been successfully studied and we have so far failed to find any adequate reference to it in the existing literature. Sabine (1923) using his formula (eqn 1) for the calculation of the absorbing power of a specimen found that the value of k (eqn. 1) is subject to a correction which varied with the varying experimental circumstances

$$a' = \frac{kV(t_1'-t_1''')}{t'_1\ t_1'''} - \frac{SP}{v}\left(\frac{1}{t_1'}\log_e\frac{I_1'}{I} - \frac{1}{t_1'''}\log_e\frac{I_1'''}{I}\right) \quad .. \quad (1)$$

Talking about this he observes . 'The magnitude, as well as the sign of this correction, depends on the intensity of the source of sound, the size of the room and the material of which it is constructed and the area of the windows opened This is illustrated in the following table (reproduced here in table 1) which is derived from a recalculation of all the rooms in which the open window experiments have been tried and which exhibits a fairly large range in these respects ' (1923)

Substituting Sabine's data (1923) for the first two cases (Table 1) in equation (1) and using the uncorrected value of k in each case, it is possible to

TABLE 1

Room.	V Cu.	I	W	k Uncorrected	Correction.	k
1. Lobby Fogg Museum 1 Pipe	96	8,800,000	1·86	0·169	0 010	0 159
2. Lobby Fogg Museum 16 Pipes ..	96	67,000,000	1·86	0·191	0·27	0·164
3. Jefferson Physical Laboratory 15 ..	202	1,700,000	5·10	0·164	0·005	0·159
4. Jefferson Physical Laboratory 1 ..	1,630	390,000	12·0	0·150	0·017	0·167
5. Jefferson Physical Laboratory 4 ..	1,960	300,000	14·6	0·137	0·024	0·161

Here W = absorbing power of the open windows, minus their absorbing power when closed.

calculate the amount of change in the absorbing power of the specimen which is due to the variation of the intensity of sound alone. When this is done we find that the absorbing power, a', in these two cases of the Fogg Museum is 2·467 units and 2·951 units when 1 and 16 organ pipes, respectively, were used. From this, it appears that the increase in the intensity of sound from 8,800,000 to 67,000,000 (arbitrary units) has produced an increase in the absorbing power of the substance amounting to about 20%.

Sabine, however, does not seem to have taken into consideration the absorption of sound by the source itself (the organ pipe and its accessories) which does absorb sound, howsoever little. If absorption due to one pipe system be equal to α_1 (same unit) then that due to 16 almost similar organ pipes would be $16\alpha_1$, nearly. Hence, it can be easily seen that by assigning different values to α_1 widely different results are obtained. It is thus clear that due to lack of data regarding α_1 we cannot come to any definite conclusion.

In view of these conflicting results, therefore, the present investigation was undertaken by the author to obtain accurate information regarding the variations in the sound-absorption coefficient due to variations in the intensity of sound. For comparison of these coefficients at different sound intensities the stationary wave method was employed and the various sources of errors inherent in the method were either eliminated or brought well under control so as to obtain reproducible results. The materials so far tested were of the 'yielding' type, such as hair-felt, ordinary thin cloth, cotton-waste and a commercial substance Treetex. A large number of experiments were performed and consistent results were obtained for each specimen. Later on, a few experiments were also performed with a ' non-yielding ' type artificial specimen made up of a large number of capillary glass tubes each of 10 cms. length, and of about 1 mm. bore. A discussion of the results is given in the last section.

Section 2. THE THEORY OF THE STATIONARY-WAVE METHOD

The theory of this method has already been worked out by E T Paris (1927) in which he has deduced eqn. (2) to calculate the sound-absorption coefficient of the substance, namely

$$\alpha = \frac{4}{2+\frac{a}{b}+\frac{b}{a}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where α is the absorption coefficient and $\frac{a}{b}$ is the ratio of the maximum amplitude to the minimum amplitude. Here by 'absorbed sound' is meant that part of the incident sound which is not reflected. To find $\frac{a}{b}$ experimentally we first determine the resistance changes ρ_1 and ρ_2 when the detecting instrument (the hot-wire microphone) inside the pipe is at the minimum pressure-variation and the maximum pressure-variation, respectively ; the mouth of the pipe having

been stopped by the specimen under test. The specimen is then replaced by a perfect reflector and the positions of the microphone to give the same resistance changes ρ_1 and ρ_2 are determined. Let these positions of the microphone be y_1 cms and y_2 cms., respectively, distant from the nearest node, the position of which is previously determined. Now, since the pressure amplitude in the stationary wave is proportional to $\sin ky$ (y is the distance from the node, $k = \frac{2\pi}{\lambda}$ and λ is the wavelength), the pressure amplitudes producing these resistance changes ρ_1 and ρ_2 must be proportional to $\sin ky_1$ and $\sin ky_2$ so that

$$\frac{a}{b} = \frac{\sin ky_2}{\sin ky_1}$$

from which α is given by

$$\alpha = \frac{4}{2 + \frac{\sin ky_2}{\sin ky_1} + \frac{\sin ky_1}{\sin ky_2}} \qquad \ldots \quad (3)$$

Section 3. APPARATUS.

(a) *The experimental pipe.*

The experimental pipe was made up of three pieces of glazed clay pipe of 30 cms. diameter (internal) and in length about 60 cms. each, with a wall-thickness of about 5 cms. These pipes were placed horizontally end to end on padded V-shaped supports, which in turn rested on a raised platform and were cemented together. One of the ends of this composite pipe opened into a wooden box $4' \times 3' \times 3'$ which served the purpose of a sound chamber. The specimens to be tested were placed at the other end of the pipe. The specimens had to be cut or shaped in a circular form so as to fit tightly into the circular mouth of the pipe which was lined all along its brim with a washer.

A circular brass-plate of about 0·25 inch in thickness, mounted permanently on a circular wooden disc, 1·5 inches thick and of about 37 cms. in diameter was always used to back the specimen. This whole system, that is the specimen backed with the perfect reflector, could be easily fitted into the mouth of the pipe and kept very rigidly in place by means of a wooden wedge which clamped its central portion as well

Since the apparatus was kept in a sequestered place in the laboratory, far away from the din of traffic and, further, since most of the experiments were performed during the night or during the quiet part of the day, no other precautions were necessary to avoid extraneous vibrations.

(b) *The source of sound.*

The source of sound was a moving-coil-type loud-speaker which was actuated by a valve-maintained tuning-fork oscillator in conjunction with a

single-stage valve amplifier. The loud-speaker was kept rigidly fixed inside the sound-chamber and was for all practical purposes fully insulated from extraneous influences.

(c) *Intensity of sound.*

To measure the intensity of sound, the oscillatory current in the primary of the loud speaker transformer was first rectified by means of a full-wave rectifier, namely a copper-oxide metal rectifier (range 1m. amp.) and then passed through a sensitive galvanometer which was shunted to bring the deflection within range. The deflection (I_R) of this galvanometer was then taken to indicate the valve of sound-intensity in terms of arbitrary units, for a given value of the current (I_m) in the field-coil of the loud-speaker. The current in the field-coil was measured by a low-resistance milli-voltmeter (in the absence of a suitable milli-ammeter). Thus the intensity of sound is ultimately read by a combination of (I_R) and (I_m) and hence any change in the value of (I_m) will mean a different intensity of sound though (I_R) may read the same.

The variations in the sound-intensity, as measured in terms of (I_R ; I_m), were effected by altering the values of (I_R) and keeping (I_m) constant. Alterations in the values of (I_R) could be brought about by altering (1) the filament current of the amplifier valve or (2) the plate-voltages of the amplifier and the oscillator valves.

By keeping the plate and the filament voltages of these valves steady and also the current (I_m), it was possible to maintain any desired intensity of sound constant to about 0·2% of itself.

To roughly estimate in decibels the order of sound intensity, the tuning fork method of Davis (1930) was employed and it was found that the intensity of sound ($I_R = 20$; $I_m = 75$) corresponded to about 25 decibels and that of sound ($I_R = 120$; $I_m = 75$) corresponded to about 55 decibels so that the range of sound-intensity employed in the present investigation was roughly from 25 to 55 d.b. Since we had no better arrangement to find out the intensity values in decibels we have thought it best to give these relative values of the sound-intensity in the arbitrary units (I_R , I_m)

The frequency of the loud-speaker note was fairly constant as it was fed by a valve-maintained tuning-fork oscillator of frequency about 511. It may, however, be remarked that the frequency of this note varied to an extent (maximum) of about 7 parts in 10,000 as we changed the intensity from its lowest value to the maximum one. This was due to the use of iron pole-pieces in the oscillator. These changes in frequency were measured by counting beats by another standard tuning fork of frequency 512 cycles per second.

(d) *Hot-wire microphone.*

The measurements of the ratio of maximum to minimum velocity amplitude inside the pipe were carried out by means of a selective hot-wire microphone of small dimensions similar to the one used by Tucker (1921, 1927),

E. T. Paris and others. The (safe) current carrying capacity of the microphone grid was about 40 milli-amperes, but it was heated by a steady current (I_g) never exceeding about 32 milli-amperes. The value of (I_g) was purposely kept low to avoid excessive heating of the grid which might give rise to evaporation effect (1914).

The microphone as a whole was rigidly supported at the end of a long rod and so arranged that its orifice always lay on the axis of the pipe for all to and fro movements of the rod and that there was no danger of tilting it during its movements inside the pipe

By moving the rod from outside, the position of the microphone inside the pipe could be varied as desired. The finer movements of the microphone were controlled by a rack and pinion arrangement. The positions of the microphone inside the pipe could be measured from outside by a comparator method using a travelling microscope reading up to 0·01 cm.

The resistance changes due to the cooling of the microphone grid by sound in the pipe were measured by means of a sensitive bridge shown in Fig. 1 up to 0·1 ohm from the (dial-type) resistance box D and to 0·001 ohm in terms of the deflection of the galvanometer G_m, the sensitivity of which was about 10^{8} amp. per mm deflection at a distance of one metre.

A similar hot-wire microphone which was mistuned and shielded from all kinds of noises was also included in the bridge-circuit outside the pipe. The mistuning and shielding of the dummy microphone was a necessary precaution to avoid all stray noises, as well as the note from the loud-speaker. Later on the dummy microphone was altogether removed with advantage. A full diagram of the electrical connections is given in Figs. 1, 2 and 3.

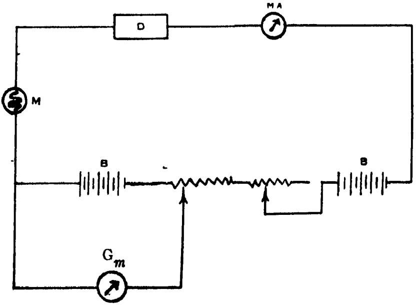

FIG. 1.

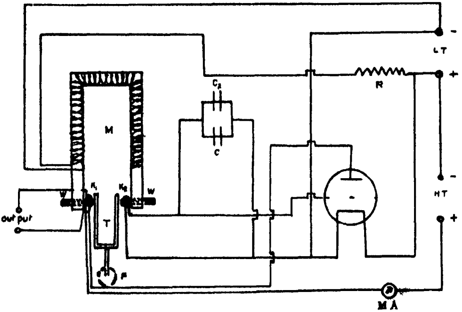

FIG 2

Circuit diagram of oscillator

R A small wire resistance
M A —Milliammeter
W—Pole pieces made of a bundle of wires
T—Tuning fork
M—Electromagnet
C_1 & C_2—Condensers
F—Base where the tuning fork was fixed
k_1 k_2—Coils wound over wooden reels

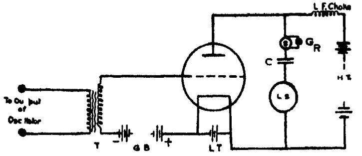

FIG 3

Circuit diagram of amplifier

T—Input transformer
C—Condenser
G_R—M.C Dead beat mirror galvanometer
G B —Grid Bias battery
L S.—M.C Loud speaker
S—Copper oxide Metal Rectifier

Section 4. METHOD OF OBSERVATION.

After tuning the hot-wire microphone in the usual way the open end of the experimental pipe was carefully closed by the specimen and allowed to remain there undisturbed till all the readings for various sound intensities were completed. This procedure was adopted in order to avoid variations in the absorption coefficient due to direct leakage of sound. Hence any absorption of sound which might be due to its direct leakage under a particular mode of closing the pipe remained constant for all the various intensities used. For a similar reason the sound chamber also was not disturbed after having been once closed. Then the current in the hot-wire grid was adjusted to some suitable value (I_g) and the steady balance point (i.e. without sound) of the spot of light from the galvanometer, G_m, was obtained The source of sound was switched on and for a given value of the intensity, the readings for ρ_1 and ρ_2 being obtained in the following manner.

The microphone was slowly shifted until it indicated a change of resistance ρ_1 which was minimum. The correct* position of the microphone corresponding to ρ_1, thus obtained, was noted down on the travelling microscope. The microphone was then kept fixed at this correct position and several readings to obtain ρ_1 were taken. The average of these readings was considered to be the most probable value of ρ_1 for that particular value of the intensity of sound

Exactly in the same manner, the position of the microphone was located at the neighbouring loop and the average value of ρ_2 (ohms), the maximum change in its resistance, due to sound of the same intensity, as before, was obtained

The procedure was repeated for different values of sound-intensity and the positions of maxima, minima and the values of ρ_1 and ρ_2 were determined in each case separately.

Determination of y_1 *and* y_2.

To determine the values of y_1 and y_2 the specimen was removed from the mouth of the pipe and the perfect reflector alone was carefully fitted and the

---

* To obtain a correct value for the minimum position the microphone was slightly displaced from its minimum position until the resistence change became ρ_1', ($\rho_1'>\rho_1$) and the corresponding position of the microphone was noted. The microphone was displaced slightly further, again in the same direction, until the resistance change became ρ_1'', ($\rho_1''>\rho'>\rho_1$) and the position of the microphone corresponding to ρ_1'' was also noted. Let these positions of the microphone corresponding to resistance changes ρ_1, ρ_1' and ρ_1'' be x_1, x_1' and x_1'', respectively. Further, the positions of the microphone corresponding to the same resistance changes ρ_1' and ρ_1'', but on the opposite side of its minimum, were also located in the same manner by displacing the microphone in the reverse direction. Let the positions of the microphone now be x' and x'', respectively. The correct position of the microphone for the minimum resistance change was then taken as an average of the readings, namely,

$$(1)\ x_1;\quad (2)\ \tfrac{1}{2}(x_1'-x')\ \text{and}\ (3)\ \tfrac{1}{2}(x_1''-x'').$$

position of the microphone, when it was located at a node, was noted down on the microscope, as previously done. The microphone was then displaced from this nodal point to such an extent that the resistance change was ρ_1, the same as was obtained in the specimen-experiment for the same intensity of sound. The value of this displacement y_1 cms. from the nodal point was then accurately measured on the microscope. By repeating this to obtain the position of the microphone, on the opposite side of the nodal point, for the same resistance change, the value of $2y_1$ cms. was also obtained.

Similarly, the value of the displacement y_2 cms. of the microphone from the node, required to produce the resistance change ρ_2 for the same intensity, was also obtained.

And in this manner the values of y_1 and y_2 were successively determined for all the intensities that were employed in the series of ρ_1 and ρ_2 determinations in the specimen-experiment without, of course, disturbing that particular mode of closing the pipe or the sound-chamber.

Finally, by measuring distances between the successive minima, the wave-length λ could be determined and the value of k $\left(k = \frac{2\pi}{\lambda}\right)$ calculated; and using this value of k in eqn. (3) the value of α for each sound-intensity could be obtained.

Section 5. Experiments.

In this section a description of the various experiments performed with the different substances, already mentioned, is briefly given and for a few typical cases the actual readings obtained during the experiment are also presented in tabular forms.

I.

Cotton-waste

The cotton-waste specimen was made by loosely packing cotton-waste into a circular wooden frame-work of the required diameter which fitted tightly into the mouth of the experimental pipe. The average depth of cotton-waste was found to be about 2 inches. An open-meshed wire gauze was also stretched across its exposed end to prevent the cotton-waste from slipping or becoming more loose during the progress of any particular experiment. This precaution was necessary for obvious reasons and it enabled us to make such a specimen retain its absorptive properties constant at least for each complete experiment, during which it was never disturbed. The specimen was backed with the perfect reflector. The readings for two different experiments with the same specimen are set down in Tables 2 and 3 and the results are plotted in Figs. 4 and 5 respectively.

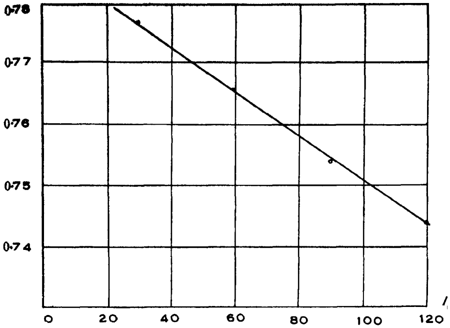
0·78
0·77
0·76
0·75
0·74
0
20
40
60
80
100
120

FIG. 4

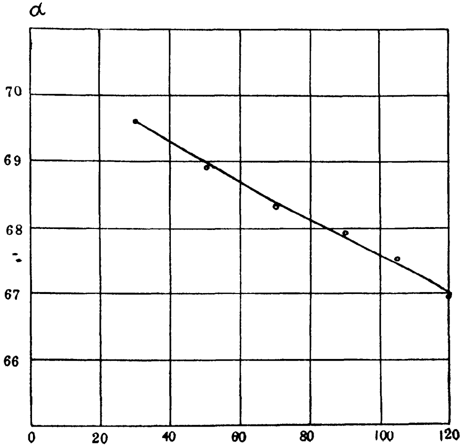
α
70
69
68
67
66
0
20
40
60
80
100
120

FIG. 5.

TABLE 2.

Specimen: Cotton-waste, 2 inches thick. $k = 0{\cdot}091$

	I_g m. amps	I_m Div.	I_R	ρ_1	ρ_2	y_1	y_2	
1	28·8	75·0	30·0	40·5 mm.	1·3 ohm + 30 mm.	2·40 cm.	7·11 cm.	0·777
2	28·8	75·0	60·0	0·3 ohm. + 9 mm.	5·8 ohm. − 10 mm	2·37 cm.	7·28 cm.	0·766
3	28 8	75·0	90·0	0·7 ohm. + 13 mm.	12·4 ohm. + 35 mm	2·32 cm.	7·39 cm.	0·754
4	28·8	75·0	120·0	1·4 ohm. + 11 mm.	18 4 ohm. − 10 mm.	2·28 cm.	7·48 cm.	0·744

TABLE 3.

Specimen: Cotton-waste, 2 inches thick. $k = 0{\cdot}090$

	I_g m. amps.	I_m Div	I_R Deflexion.	ρ_1	ρ_2	y_1 cms.	y_2 cms.	
1	32·1	75·0	30·0	39·0 mm.	0·7 ohm. − 10 mm	2·730	11·05	0·696
2	32·1	75·0	50·0	104·0 mm.	2·3 ohm. + 20 mm	2·680	11·10	0·689
3	32·1	75·0	70·0	0·2 ohm. + 33 mm	5·4 ohm.	2·650	11·22	0·683
4	32 1	75·0	90·0	0·4 ohm. + 6 mm.	10·8 ohm.	2·640	11·35	0·678
5	32·1	75·0	105·0	0·5 ohm. + 54 mm.	15·9 ohm	2·635	11·50	0·675
6	32·1	75·0	120·0	0·8 ohm. − 20 mm.	21·4 ohm.	2·620	11·65	0·669

II.

Treetex

The next substance under test was Treetex—a fibrous substance of fairly high absorbing properties. The average thickness of the substance is about 0·6 inch and, according to the manufacturers, the value of its sound-absorption coefficient is approximately 30%. Three pieces were cut from a sheet of Treetex and joined together so as to form a disc of the required size (37 cms. diameter). It was then mounted on the perfect reflector as usual. The cutting into pieces and then joining into a disc was purposely done to get the joints and to discourage vibration (if any) as a whole, of the specimen. Table 4 contains the readings of the experiment with Treetex, the result is shown in Fig. 6.

TABLE 4.

Specimen: Treetex about 0·6 inch thick. $k = 0{\cdot}092$

	I_O m amps.	I_m Div.	I_R Deflexion	ρ_1	ρ_2	y_1	y_2	α
1	29·2	75 0	30·0	14 0 mm.	2·10 ohm.	1 05 cm.	13·22 cm	0 338
2	29·2	75·0	60·0	55·0 mm.	8·65 ohm.	1·03 cm.	13·50 cm.	0 331
3	29·2	75·0	75·0	0·1 ohm. + 18 mm.	12 55 ohm.	1·00 cm.	13 75 cm	0·321
4	29·2	75 0	90·0	0 2 ohm. − 16 mm.	16·25 ohm.	0·92 cm	13·80 cm	0 299
5	29·2	75 0	100·0	0 2 ohm. + 14 mm.	18·20 ohm.	0·955 cm	13·40 cm	0 311
6	29 2	75·0	120·0	0·3 ohm. + 12 mm	22·55 ohm	0·975 cm	13·20 cm	0·319

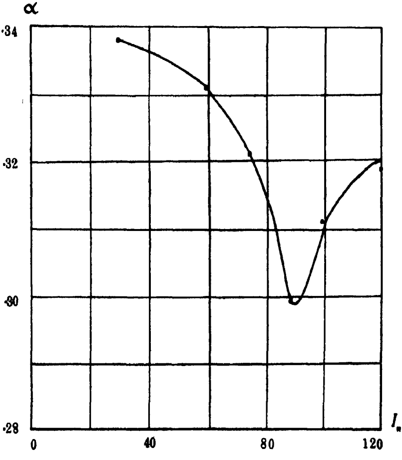

FIG. 6.

III.

Hair-felt.

The third substance tested was coarse hair-felt about 0·4 inch thick. It was cut into a circular form and mounted on the perfect reflector in such a manner that there was no space left between the felt and the perfect reflector The data for an experiment with this substance are set down in Table 5 and the result plotted in Fig. 7. A different piece of hair-felt, fresh from the market

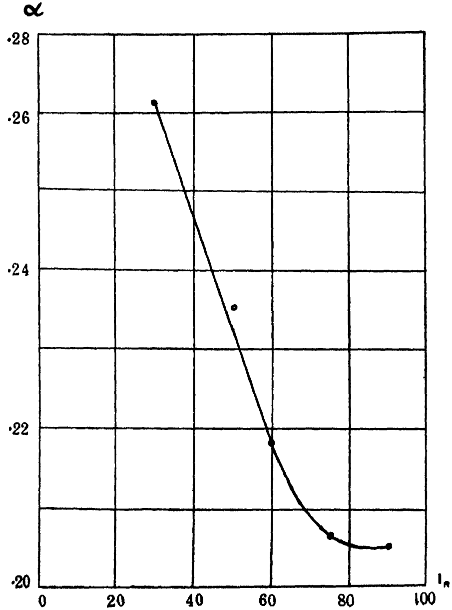

FIG. 7.

and about 0·5 inch thick, was also tested. The typical readings for this specimen are shown in Table 6 and the result plotted in Fig. 8.

TABLE 5.

Specimen: Hair-felt about 0·4 inch thick. $k = 0{\cdot}90$

	I_G m. amps	I_m Div.	I_R De-flexion.	ρ_1	ρ_2	y_1	y_2	α
1	27·8	65 0	30·0	1·0 mm	0·86 ohm.	0 70 cm.	11 00 cm	0 261
2	27·8	65·0	50 0	2·5 mm.	2·70 ohm	0 63 cm	11 20 cm.	0 235
3	27·8	65 0	60·0	3 0 mm.	3 80 ohm.	0 58 cm.	11 30 cm.	0 218
4	27 8	65 0	75·0	5·0 mm	6 70 ohm	0 55 cm	11 45 cm	0·206
5	27·8	65·0	90·0	7·0 mm	9 50 ohm.	0 55 cm	11·55 cm	0 205

TABLE 6.

Specimen: Hair felt 0 6 inch thick. $k = 0{\cdot}09$

	I_G m. amps.	I_m Div.	I_R De-flexion. mms.	ρ_1	ρ_2	y_1 cms	y_2 cms	α
1	32 5	75·0	20 0	4 5 mm	1 3 ohm	0 900	12 30	0 304
2	32 5	75 0	30 0	8 0 mm	2 10 ohm	0 895	12·65	0 299
3	32 5	75 0	40 0	11·5 mm.	2·85 ohm.	0 895	12 80	0·298
4	32 5	75 0	60 0	18 5 mm	5 2 ohm	0 880	13 05	0 292
5	32 5	75·0	80 0	27 5 mm.	7 8 ohm	0 875	13 10	0·290
6	32 5	75·0	100 0	40 0 mm	10 15 ohm	0 875	13 14	0 289
7	32 5	75 0	120 0	52 5 mm	13 4 ohm	0 855	13 19	0·283
8	32 5	75 0	140 0	64 0 mm	17·3 ohm	0 810	13 33	0 269
9	32 5	75 0	150 0	68 5 mm	19·1 ohm	0 815	13 25	0 271
10	32 5	75 0	160 0	73 0 mm	20 9 ohm	0 815	13 20	0·272
11	32 5	75 0	180 0	94 5 mm	23 1 ohm	0 885	13 10	0 292
12	32·5	75·0	190 0	106 0 mm	24 1 ohm	0 895	13 00	0 296

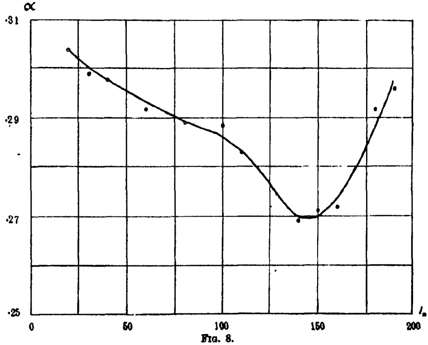

FIG. 8.

IV.

Tool.

The fourth substance tried was 'Tool' (Hindustani name for a kind of thin red cloth of coarse texture). It was mounted on the perfect reflector. The readings for this substance are set down in Table 7 and the result plotted in Fig. 9.

TABLE 7.

Specimen: Tool, single layer about 0·5 mm. thick. $k = 0.089$

	I_G m. amp.	I_m Div.	I_R Deflexion.	ρ_1	ρ_2	y_1 cm.	y_2 cms.	α
1	28·8	70	50	7·5 mm.	7·95 ohm.	0·300	14·48	0·105
2	28·8	70	82	24·0 mm.	18·53 ohm.	0·285	14·48	0·100
3	28·8	70	110	43·0 mm.	26·67 ohm.	0·280	14·52	0·098

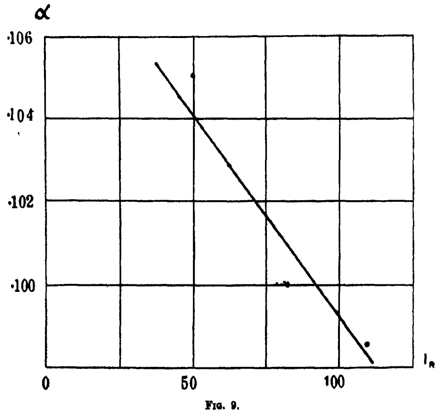

FIG. 9.

V.

Capillary-tube-specimen.

This artificial specimen was made by arranging perpendicularly a large number of thin capillary tubes in a cylindrical vessel whose diameter was about 15 cms. and height about 11 cms. The length of each capillary tube (vaccine tube) was 10 cms. and its average bore was estimated to be about 0·1 cm. by measuring the bores of a few typical tubes of the lot. The average thickness of the wall of the tube was of the order of 0·02 cm The number of tubes required to fill this vessel completely was about 9,000. This specimen had mostly two types of capillary channels depicted in Fig. 10 by (*a*) and (*b*). The number of (*b*) type channels in the honey-comb structure of the specimen was estimated to be about the same as that of the (*a*) type channels, i e , 9,000 The cross-sectional area of the total (*b*) type channels was about 8% to 10%

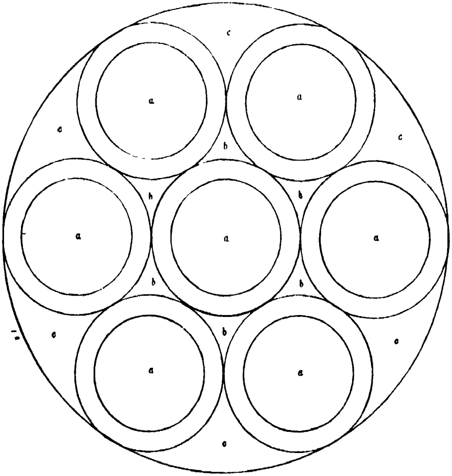

FIG. 10.

of the cross-sectonal area of the total (*a*) type channels. Further, the dimensions of the specimen and the density of glass being known, the total area of perforation was calculated to be 98 sq. cms. approximately. Hence, the ratio of the perforation to the total area was equal to 0·55.

In performing experiments with the above specimen, the experimental pipe (internal diameter 30 cms.) was replaced by a smaller pipe of internal diameter 15 cms. and of length 180 cms. The specimen, described above, could be easily placed tightly inside the mouth of the experimental pipe and backed with a heavy perfect reflector, which consisted of a brass plate 0 25 thick permanently mounted on a wooden disc ($1\frac{1}{2}''$ thick) and of diameter about 20 cms.

The readings for the experiment performed with this specimen are set down in Table 8 and the result plotted in Fig 11.

TABLE 8.

Specimen Capillary glass-tube assemblage $\lambda = 0\ 09$

	I_G in amp	I_m Div	I_R Deflexion, mms	ρ_1	ρ_2	y_1	y_2	α
1	28 1	70 0	30	0 1 ohm +15 mm	6·0 ohm +25 mm	2·34 cm.	11 62 cm.	0 627
2	28 1	70 0	60	0 2 ohm + 18 mm	11 6 ohm	2 34 cm	11 73 cm	0 625
3	28 1	70 0	100	0 4 ohm +35 mm	19 3 ohm	2 32 cm	11 80 cm	0 620
4	28·1	70 0	150	0 8 ohm -15 mm	27 7 ohm	2 32 cm	12 04 cm	0 616
5	28 1	70 0	200	1 3 ohm +5 mm	31 5 ohm	2 32 cm	12 40 cm	0 610
6	28 1	70 0	230	1 8 ohm +10 mm	35 6 ohm	2 31 cm	12 60 cm	0 605
7	28·1	70 0	270	2 8 ohm −5 mm	38·3 ohm.	2 31 cm	12 82 cm	0·601

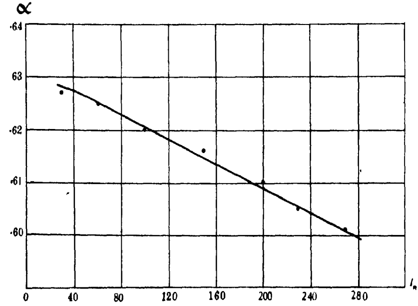

FIG. 11.

Section 6. RESULTS.

In this section the results of experiments are presented separately for each specimen tested and a general discussion of the same is also appended

1. *Cotton-waste*

From Tables 2 and 3, and Figs. 4 and 5, it may be readily seen that an increase in the intensity of sound incident normally upon the above specimen produces a marked decrease in its absorption coefficient and that this decrease is almost a linear one By taking an aggregate of several results, it is found that a change in the intensity of sound from 25 d b to about 55 d b causes a decrease in α of the order of 4 to 5% of itself

2. *Treetex*

It is interesting to note that the curve (Fig 6) depicting the variation of the absorption coefficient of Treetex with intensity indicates a minimum value of the same Increase in the intensity of sound from 25 d b. upwards is found to produce, at first, a continuous decrease in α up to about 40 d b and for further increments up to 55 d b α is found to increase continuously The maximum decrease in α was of the order of 10% of its value corresponding to the intensity of about 25 d b.

3 *Hair-felt*

The α-intensity curves (Figs 7 and 8) for the two different samples of this substance also show a minimum value of α corresponding to an intensity somewhere between 45 d b and 50 d b. This decrease in α at the minimum is of the order of 25% of its value corresponding to 25 d b

4. *Tool.*

The α-intensity curve (Fig. 9) obtained for this substance shows a linear decrease of α which is of the order of 7% of itself for a change of intensity from 25 d b. to 45 d.b The variation of α for this substance is more or less similar to that obtained for cotton-waste.

5. *The glass-tube specimen.*

The absorption coefficient of this artificial substance is found to decrease with intensity (almost linearly) in a manner depicted by the curve shown in Fig. 11. The decrease in α is between 6% to 7% of its value for a change of intensity from 25 d.b. to about 60 d b.

From the results given above it may be gathered that in the case of the felted substances, so far tested, the value of absorption coefficient, at first, decreases with the intensity of sound until it reaches a minimum value, after

which it begins to increase with further increase in the intensity. Whereas in all other cases α is always found to decrease with the intensity of sound up to about 60 d.b., the highest intensity employed in the test. Whether for still higher intensities these substances will also have a minimum value of α is a matter that requires further investigation

Section 7 DISCUSSION OF RESULTS

The ' perfect ' reflector which was used in these experiments never fulfilled the condition of the ideal reflector demanded by the theory of the method (§2) and so the waves inside the pipe were not perfectly stationary From the deflection of the galvanometer, obtained at a nodal point in such a stationary wave-system, the absorption*-coefficient of the reflector was calculated to be of the order of 0 015 and, hence, its reflection coefficient was only 98·5%, approximately, instead of 100% required by the theory From the practical point of view, however, this slight defect of the reflector could be safely ignored; and also since it remained constant for all the intensities used it could not vitiate the observed results

The perfect reflector being very thick and heavy there could have been little chance of its vibration under the pressure of waves (frequency 511), especially when its central portion was also rigidly clamped by the wooden-wedge (§3) This was proved by the fact that the nodal point in the stationary wave pattern, when the perfect reflector alone was used, did not indicate any shift in their position with variations in the sound intensity Consequently, there was no possibility of the specimen (backed by the perfect reflector) behaving like a light panel and changing its transmittance with variations in the intensity of sound incident upon it. The employment (in the test) of every inelastic substance, like cotton-waste, is also an assurance that the observed variations in the absorption coefficient with intensity were free from this error

It may be recalled that the maximum variation in the frequency of the note employed in the test was of the order of about 7 parts in 10,000 and this must have slightly decreased the sensitivity of the tuned hot-wire microphone This factor, however, cannot affect the value of α because at any particular intensity (hence frequency) the microphone has absolutely the same sensitivity while taking readings for ρ_1 and ρ_2 as that for y_1 and y_2. The variations in α due to slight changes in the frequency of the note, in the present case, are negligible ; in fact, for hair-felt half an inch thick, this can be shown, from the already existing data (1936), to be of the order of 0·0001 ; and in cases other than hair-felt it is still smaller.

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* This includes all energy losses due to leakage, transmission, etc of sound from the end of the pipe in which the reflector is tightly fitted.

The oscillogram of the oscillatory current from the tuning-fork oscillator (Fig 12) shows that the current which actuated the speaker was not sinusoidal But the components present were remote from 512 and so they could not have influenced the detecting instrument which was highly selective in character and tuned to a frequency of 511 cycles per second

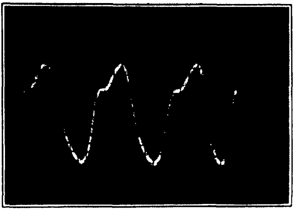

FIG 12

Finally, to be more certain of the observed results the experiments were repeated by replacing (1) the hot-wire microphone by another of similar design and make, and (2) the full-wave rectifier by another rectifier and later on by a suitable vacuum thermocouple The experimental pipe and the sound-chamber were also replaced and under all circumstances the same type of results were obtained

Section 8 A POSSIBLE EXPLANATION OF THE OBSERVED DECREASE IN THE VALUES OF THE ABSORPTION COEFFICIENT WITH INCREASE OF INTENSITY OF SOUND

The results given in section (6) indicate a decrease of absorption coefficients of various substances In the case of hair-felt and Treetex the decrease is as much as 25 and 10%, respectively, while in the case of cotton-waste and vaccine tubes the decrease is much less, viz 5 and 7%, respectively. Now, a decrease in the value of the absorption coefficient means an increase in the value of the reflection coefficient

$$\dot{\xi}_r / \dot{\xi}_i$$

given by

$$\frac{\dot{\xi}_r}{\dot{\xi}_i} = \frac{\rho'c'/\rho c - 1}{\rho'c'/\rho c + 1} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

where $\frac{\rho' c'}{\rho c}$ represents the ratio of the acoustic impedances of two media. If the reflection occurs at the surface of a porous material, then this ratio is given by

$$\frac{\rho' c'}{\rho c} = 1 + (1 - i)\frac{\Delta}{4\pi} \qquad . \qquad .. \qquad . \qquad (5)$$

where the porous material is considered to be an assemblage of a large number of fine tubes of radius 'a' and Δ is the thickness of the laminar shell which is discussed in the following paragraphs.

It was first suggested by Stokes that during sound transmission through tubes there arises a frictional force which causes damping to the sound waves This frictional force is considered to be due to a layer of fluid on the surface of the tube which is in laminar motion ; the thickness of this layer is very small and is given by Δ, which from theoretical considerations is found to be

$$\Delta = 2\pi\sqrt{\frac{2\nu}{\omega}} \qquad . \qquad . \qquad (6)$$

where ν represents the kinematic viscosity and $\frac{\omega}{2\pi}$ the frequency of vibration. This view has been supported by Lamb, Rayleigh and others Thus we come to a startling conclusion that to account for the decrease of absorption coefficient for a tube of given radius the value of Δ must increase with intensity of sound waves, that is, the thickness Δ of the laminar layer must increase From our experiments, however, it is not possible to calculate the value of Δ It may be noted in this connection that formulas (4) and (5) are based on a theory which assumes that the porous substance at which reflection occurs is an ideal substance which is a regular assemblage of a large number of similar channels of circular cross-section and thin wall, uniformly distributed and bounded by surfaces everywhere perpendicular to the face. It is, therefore, evident that even our vaccine tube specimen does not come up to the mark, as there are in it two types of channels (§5, Fig. 10) of a widely different nature, (b-type channels are not circular) and, hence, the reflection at such a surface is a complicated affair.

According to the theory developed by Sexl (1928), the particle velocity u at any radial distance r, in the case of alternating flow through a tube of radius 'a', is given by

$$u = c_1\{(\text{ber}\ \alpha a - \text{ber}\ \alpha r)\sin\omega t + (\text{bei}\ \alpha a - \text{bei}\ \alpha r)\cos\omega t\} \qquad .. \qquad (7)$$

where

$$\alpha = \left(\frac{\omega}{\nu}\right)^{\frac{1}{2}} \quad \text{and} \quad \frac{\omega}{2\pi} = \text{frequency.}$$

It is found that for small values of $\omega_{\to 0}$ the velocity u follows Poissieulle's law, viz. .

$$u = (a^2 - r^2)\,\frac{P_1 - P_2}{4l\eta}.$$

While when αa is large corresponding to increasing frequency, it is found that the velocity is practically constant along the radius except near the surface of the tube where the velocity vanishes Thus we find that near the surface of the tube there exists a layer where the motion is laminar

Experiments on alternating flow through tubes have been performed by Richardson and Tyler (1930) who have measured the velocity gradient in a transverse direction near the mouth of pipes , their result confirms the above theory in a most remarkable manner The thickness of the laminar layer Δ has been found to vary with frequency in the manner predicted by the theory, viz

$$\Delta \propto \omega^{-\frac{1}{2}}.$$

The phenomenon near the open end of the pipe (at the other end a vibratory piston worked) is found to be very complicated, the peaks become very prominent and sharp and the velocity gradient along the radius does not follow Sexl law As we recede from the open end, the peaks become less prominent and shift their position with respect to the wall of the tube (Fig 13) The shift is towards the wall indicating a decrease in the value of Δ. With an increase of frequency, the same phenomenon is found to repeat itself with greater prominence and sharpness (Δ is measured from the peak to the surface of the pipe)

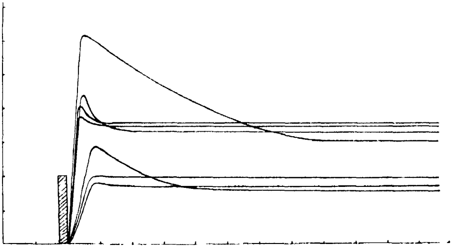

FIG 13.

Curves showing velocity of air particles measured along the radius of the pipe at varying distances from the mouth of the pipe.

These results are of great consequence in the calculation of acoustic impedance at the open end of a tube In calculating the impedance we generally assume that the type of motion at the open end is exactly the same as in the interior. According to experiment, however, we find that this is not the case Hence, the impedance as calculated on the above basis will not represent the true value indicated by eqn (5). We have already observed that the value of Δ near the open end is entirely different from that which exists in the interior of the tube. There is a decided increase in the value of Δ at the open end Thus, the calculated value of the reflection coefficient will be larger and hence the absorption coefficient α for a porous material will be smaller than that calculated on the basis of formula (4)

But we have so far no direct experimental evidence to support the view that Δ near the open end undergoes a further change in the value with the increase of the intensity of sound waves It has been found during the course of the determination of the nodal point that the latter shifts its position with the intensity.* Since the wave-form is not sinusoidal but shows the presence of

* The shift of the nodal point observed in the case of cotton waste and hair felt are set down in tabular form below.—

A. Cotton-waste

	Intensity I_m	Intensity I_R	Total shift centimetres	Relative shift of nodal point cms	Percent of total shift	α Approx.
1	75	30	4 84	0 00	0 0	0 77
2	75	60	4 79	0 05	1 0	0 76
3	75	90	4 69	0 15	3 1	0 75
4	75	120	4 65	0 19	4 0	0·74

B Hair felt.

	Intensity I_m	Intensity I_R	Total shift cms	Relative shift of nodal point cms	Percent of total shift	α Approx
1	75	30	1 73	0 00	0 0	0 24
2	75	50	1 70	0 03	1 7	0 23
3	75	70	1 65	0·08	4 6	0 22
4	75	90	1·60	0·13	7 5	0 21
5	75	120	1·62	0 11	6·4	0 22

Here the total shift is the difference between positions of the nodes with the perfect reflector and with the specimen, respectively.

other components (Fig 12), the phenomena at the surface of the porous material must become more complicated and the interpretation of the results become difficult. But the hot-wire microphone, coupled with the resonator, being a selective instrument there is no doubt that the nodal point, for the particular frequency, shifts with the increase of intensity On the basis of physical independence of motion of different frequencies, we might assume that the nodal point near the surface of porous material will also undergo a shift. In the case of a porous material, the nodal point is virtually inside the porous body With the increase of intensity the nodal point shifts towards the open end, and if the experimental evidence of Richardson and Tyler be taken into consideration we find a ready explanation of the increase of Δ

Richardson (1926) has also pointed out that Δ varies with the roughness and the elasticity of the material of the tube A large number of experiments performed to determine the tube-correction (1933) to account for the diminution in the velocity of sound in tubes also seem to indicate the dependence of Δ on the two factors mentioned above

The phenomena, however, requires further investigation with pure sinusoidal notes before any definite conclusion can be drawn regarding (1) the shift of the nodal point, and (2) the changes in the value of Δ near the open end at high frequencies The theory so far known relates, it must be observed, to the phenomena inside the tube

In conclusion I should like to offer my thanks to Professor M N Saha, F R S , for his kindly interest and to Dr R N Ghosh, D Sc , for his critical suggestions and help throughout the work I also wish to express my thanks to the authorities of the Osmania University of Hyderabad, particularly Pro-Vice-Chancellor Qazi Mohammad Husain, for granting a scholarship which enabled me to stay at Allahabad and carry out this work

Abstract

An experimental study of the variation of sound-absorption coefficient α with intensity of sound was made by means of the stationary-wave-method The materials employed in the investigation were (1) cotton-waste, (2) treetex, (3) hair-felt, (4) tool (a kind of thin cloth) and (5) an artificial specimen, which was an assemblage of a large number of capillary glass-tubes It is observed

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The virtual node in the case of a specimen is situated somewhere inside the body of the specimen and so, in other words, the total shift is the distance of the virtual node from the surface of the specimen It may be noted (Tables A and B) that as α decreases the virtual node shifts towards the surface of the specimen, and in the limit, that is when $\alpha_{\to 0}$ (Perfect Reflector) the virtual nodal point is at the surface of the substance and hence there is no shift of the nodal point with variations of the intensity of sound

During the shift-measurement experiment, the room temperature was almost constant and the effect of change in frequency of the note (7 parts in 10,000) on the quarter wave length, and hence on the shift, is negligible.

that an increase in the intensity of sound causes an appreciable decrease in the absorption coefficient of these substances For an increase in sound-intensity from 25 d.b. to about 55 d b, the decrease in α, in the case of cotton-waste and tool, is found to be linear and about 5% and 6% (of itself), respectively. In the case of felted substances (2) and (3), α at first decreases with intensity and after reaching a minimum value begins to increase with further increment in sound-intensity. The maximum decrease in α for (2) and (3) is as much as 15% and 25% (of itself), respectively. In the case of glass-tube specimen the decrease in α is about 7% for a change of intensity from 25 d b. to about 60 d b.

In explaining the results, the idea is put forward that an increase in the intensity of sound-waves increases the thickness of the layer of laminar flow or the 'skin' of gas which exists at the surface of the tube when the gas oscillates.

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HEAT OF IONIC DISSOCIATION OF IODIDES OF RUBIDIUM AND LITHIUM AND ELECTRON AFFINITY OF IODINE

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(Communicated by Prof M N Saha, F R S)

There are various methods, chiefly spectroscopic, for determining the heat of dissociation of diatomic molecules into neutral atoms Some of these have been employed for experimentally determining the heat of dissociation of most alkali halides into their constituent atoms From a knowledge of this the heat of dissociation of an alkali halide MX into an ionised alkali atom M^+ and a negative halogen ion X^- can be calculated if the ionization potential of the alkali and the electron affinity of the halogen atom are known The heat of dissociation of an alkali halide into its constituent ions will be briefly termed as 'heat of ionic dissociation' There is, however, a direct thermal method for determining this heat of ionic dissociation which has been employed by J E Mayer (1930) and his co-workers and in this laboratory by M N Saha and A N Tandon (1936) The principle of this method is to lead the alkali halide vapour MX into a chamber maintained at a high temperature and estimate the quantity of M^+ and X^- ions formed as a result of thermal dissociation by measuring the respective ionic currents obtained by the effusion of these ions through a narrow orifice From such measurements the concentration of the ions can be found The vapour pressure of the alkali halide is known from the temperature of the subsidiary furnace We can then determine the equilibrium constant of ionic dissociation from which the heat of ionic dissociation is easily calculated with the help of the usual dissociation formula

J E. Mayer (1930) investigated the ionic thermal dissociation of iodides of cæsium and potassium from which he derived the heat of ionic dissociation This enabled him to calculate the electron affinity of iodine by making use of the Born cycle J E Mayer later on with L Helmholtz (1932) worked with RbBr and NaCl M N Saha and A N Tandon (1936) studied the dissociation of KCl, NaCl and LiCl and determined the electron affinity of chlorine A N Tandon (1937) worked with KBr and NaBr and KI and NaI and found the electron affinities of bromine and iodine In the present paper the dissociation of iodides of rubidium and lithium has been investigated with an improved apparatus and the method of calculation has been freed from certain inaccuracies occurring in the previous papers The lattice energy of the alkali halide and the electron affinity of iodine has also been deduced.

Among other interesting methods employed for experimentally determining the electron affinity of iodine may be mentioned those of P. P Sutton and J. E. Mayer (1935) and of G. Glockler and M Calvin (1937) The values of

this quantity from all determinations up-to-date, experimental as well as theoretical, are collected in Table 7.

On the theoretical side the most important work is that of Max Born and J. E. Mayer (1932) who have improved upon the older theory of ionic crystals by taking into account some additional factors and obtained a formula for the lattice energy which has been utilised by L Helmholtz and J. E. Mayer (1932), Mayer and Maltbie (1932), Mayer (1933), Mayer and Levy (1933) for calculating the lattice energies of the alkali halides and some other simple salts. M. L. Huggins (1937) has recalculated the lattice energies by taking into account more recent data. From these results the heat of ionic dissociation as well as the electron affinities can be calculated.

Theory

When the alkali iodide vapour MI enters the region of high temperatures the following reactions take place.—

$$MI \rightleftarrows M+I-D, \qquad (1)$$

$$MI \rightleftarrows M^{+}+I^{-}-Q, \qquad (2)$$

$$M \rightleftarrows M^{+}+e-I_{M}, \qquad (3)$$

$$I^{-} \rightleftarrows I+e-E_{X}, \qquad (4)$$

$$I_{2} \rightleftarrows 2I-D', \qquad (5)$$

where D is the heat of atomic dissociation of the alkali halide, Q the heat of ionic dissociation, I_M the ionization potential of the alkali M, E_X the electron affinity of iodine and D' the heat of dissociation of the iodine molecule It may be emphasized that the conditions of equilibria of all the five reactions must be individually and simultaneously satisfied no matter what be the concentration of any of the components, provided only that all are present in the reaction space. Thus even if from any cause any component is present in much greater or smaller concentration the other components so adjust themselves that the dissociation formula is satisfied and the dissociation constant is always given by the usual thermodynamic formula. Hence the presence of excess of electrons due to thermionic emission from graphite does not affect the value of the dissociation constant. It can be shown from thermodynamic theory that the dissociation constant K_2 of the reaction (2) is given by the formula

$$\log K_2 = \log \frac{p_{M^+}\, p_{I^-}}{p_{MI}} = -\frac{Q}{2{\cdot}3RT}+\frac{3}{2}\log T+\log\left(1-e^{-h\nu/kT}\right)$$
$$+\log\left[\frac{k^{5/2}}{2^{3/2}\,\pi^{1/2}\,Ih}\left(\frac{m_{M^+}\,m_{I^-}}{m_{MI}}\right)^{3/2}\right], \qquad (6)$$

where ν is the frequency of linear vibration of the atoms in the molecule of the gaseous halide MI, I the moment of inertia of this molecule and m_{M^+}, m_{I^-}, m_{MI} the masses of the ion or the molecule. The other dissociation constants are given by the following relations —

Dissociation into atoms:

$$\log K_1 = \log \frac{p_M p_I}{p_{MI}} = -\frac{D}{2\cdot 3RT} + \frac{3}{2}\log T + \log\left(1-e^{-h\nu/kT}\right)$$
$$+\log\left[\frac{k^{3/2}}{2^{3/2}\pi^{1/2} Ih}\left(\frac{m_M m_I}{m_{MI}}\right)^{3/2}\right] + \log 8 \quad . \quad (7)$$

Ionization of the atom

$$\log K_3 = \log \frac{p_{M^+} p_e}{p_M} = -\frac{I_M}{2\cdot 3RT} + \frac{5}{2}\log T + \log \frac{(2\pi m_e)^{3/2} k^{5/2}}{h^3}. \quad (8)$$

Formation of negative halogen ion.

$$\log K_4 = \log \frac{p_I p_e}{p_{I^-}} = -\frac{E_\lambda}{2\cdot 3RT} + \frac{5}{2}\log T + \log \frac{(2\pi m_e)^{3/2} k^{5/2}}{h^3} + \log 8 \quad . \quad (9)$$

Dissociation of the halogen molecule into atoms

$$\log K_5 = \log \frac{p_I^2}{p_{I_2}} = -\frac{D'}{2\cdot 3RT} + \frac{3}{2}\log T + \log\left(1-e^{-h\nu/kT}\right)$$
$$+\log\left[\frac{m_I^{3/2} k^{3/2}}{4\pi^{1/2} Ih}\right] + \log 16 \quad .. \quad (10)$$

Also from considerations of Born's cycle we get

$$E_\lambda = D + I_M - Q, \quad . \quad (11)$$

and the lattice energy $\phi(r_0)$ is given by

$$\phi(r_0) = Q + L_{MI}, \quad . \quad .. \quad .. \quad (12)$$

where L_{MI} is the heat of sublimation of MI at the absolute zero.

APPARATUS.

The demountable vacuum graphite furnace used in these experiments has been described in detail by M. N. Saha and A. N. Tandon (1936) but the internal arrangement followed in the present work is slightly different from theirs and is shown in Fig. 1. The improvement consists in a device for applying a magnetic field to distinguish between the negative ion current and the electron current, and in the design of the auxiliary furnace. High temperature is produced in the graphite tube F which is heated by a current of the order of a thousand amperes from a low-tension transformer. This tube has a fine

circular hole on one side while on the other side there is a conical cavity C in which a hollow conical plug P of graphite fits gas-tight. The tube was so made

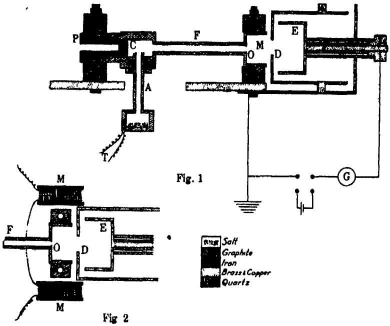

Fig. 1

Fig 2

that its wall near the junction of the auxiliary furnace A was thicker on one side of the cavity than on the other so that the auxiliary furnace could be fitted gas-tight with the help of screw and collar arrangement. This furnace was thus heated simply by conduction from the graphite furnace F so that by using tubes of different lengths and wall-thicknesses the desired temperatures could be obtained These were adjusted by trial. The auxiliary furnace is made thicker at the bottom where the salt is kept so that the temperature gradient in the neighbourhood of the salt is very small, while the nickel-nichrome thermocouple is inserted in the wall. The tube was easily constructed by boring it through and closing the bottom by a tightly-fitting plug. The tube could be readily replaced by another without disturbing the graphite furnace itself Another advantage of this form of the auxiliary tube lies in the fact that the vapour molecules first impinge on the wall of the graphite furnace and thereby lose their mass velocity and afterwards move with the thermal velocity characteristic of the temperature of the furnace Care was taken to see that the salt vapour does not condense on the plug closing the furnace F. For this purpose the plug was made hollow and long enough so that it projected much beyond the clamping carbon blocks and reached up to the junction of the auxiliary tube. The wall of the graphite furnace in the middle is so thin that an actual comparison of the temperature inside F as measured by a platinum platinum-rhodium thermocouple with that of the outer surface of F as measured

by a disappearing filament pyrometer showed no greater difference than the uncertainty in the pyrometer readings itself. Theoretical calculations from conductivity considerations also show that the difference would be negligible It was therefore neglected.

The vapour molecules suffer dissociation inside F according to the equations already given and the products of dissociation effuse out through the narrow orifice after which they traverse a magnetic field produced by two electromagnets shown separately in Fig. 2 These were constructed by winding several layers of bare copper wire over iron bobbins carefully insulated by mica and two such electromagnets were arranged on opposite sides of the effusing beam. Suitable currents were passed so that the electrons were deflected and the negative ion current alone measured

The rest of the arrangement is identical with that of Saha and Tandon The effusion beam is limited by a diaphragm D Behind this is a Faraday cylinder connected to a sensitive galvanometer Suitable accelerating or retarding potentials can be applied between the Faraday cylinder and the limiting diaphragm in order to collect the ions of the desired charge

Let the hole of the diaphragm be coaxial with the effusion hole If the diaphragm subtends a cone of semi-vertical angle θ_0, then the number of particles effusing out through the hole of area S and passing through the limiting diaphragm is equal to

$$S \int_{c=0}^{c=\infty} \int_{\theta=0}^{\theta=\theta_0} n_c dc \cdot \frac{1}{2} \sin\theta \, d\theta \quad c\cos\theta = \frac{1}{4} n\bar{c} S \sin^2\theta_0 = \frac{1}{4} n\bar{c} S \frac{r^2}{r^2+d^2},$$

where r = radius of the diaphragm and d its distance from the effusion hole The galvanometer current

$$i_g = \frac{1}{4} n\bar{c} Se \frac{r^2}{r^2+d^2}. \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

But

$$n = p/kT \quad \text{and} \quad \bar{c} = \sqrt{\frac{8kT}{m\pi}},$$

hence

$$i_g = \frac{epS}{\sqrt{2m\pi kT}} \cdot \frac{r^2}{r^2+d^2} \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

The equilibrium constant K_2 is therefore given by the relation

$$K_2 = \frac{p_{M^+} p_{I^-}}{p_{MI}} = \frac{2\pi kT}{e^2S^2} \left(\frac{r^2+d^2}{r^2}\right)^2 \frac{\overset{+}{i_g}\,\overset{-}{i_g}}{p_{MI}} \sqrt{m_{M^+} m_{I^-}} \quad \ldots \quad (15)$$

By combining this equation with (6) and substituting the values of the other quantities Q is found out. The various data utilized in this paper are given in Table 1.

TABLE 1

Salt	Moment of inertia of molecule in gaseous state $\times 10^{38}$ gm cm^2	Characteristic frequency of vibration of molecule in gaseous state in cm^{-1}	Heat of dissociation into neutral atoms in kilocals	Heat of ionization of alkali in kilocals	θ (Debye)	λ_0 in kilocals	Compressibility at 0°C per dyne $\times 10^{12}$	Temperature coefficient of compressibility per dyne $\times 10^4$	Volume coefficient of expansion per degree $\times 10^4$	Temperature coefficient of expansion coefficient $\times 10^4$
RbI	6 64	179	76 7	96 0	113	46 4	9 58	6	12	6 5
LiI	0 401	1800	81 6	123 8		38 7				

EXPERIMENTAL TECHNIQUE

First the graphite tube was thoroughly degassed by heating it at a temperature much higher than that at which the experiment is to be performed After prolonged degassing for several hours the behaviour of the tube became regular and the ion currents from the empty tube diminish to a negligible value At the temperature of the experiments about 1500° C the positive ion current is extremely small while the negative ion current though much greater is still much less than the current obtained when the salt is put in the furnace The following observations (Table 2) obtained with the tube near about the final state will give an idea of the currents in the blank experiment —

TABLE 2

Accelerating voltage—2 volts

Sensitivity of galvanometer—1 13 $\times$ 10^{-9} amp /mm

Temperature of graphite tube °C	NEGATIVE DEFLECTION IN MM		POSITIVE DEFLECTION IN MM	
	Without magnetic field	With 3 amperes through electro magnet	Without magnetic field	With 3 amperes through eletro magnet
1400	3	0	0	0
1455	20	4	1 5	2 5
1500	44	11	3 5	5
1540	80	16	6	8

It can be shown from theoretical considerations that the deflection of the ion beam under the influence of the magnetic field will vary as $1/\sqrt{m}$ Hence it will be greater for the lighter ion and by this means the electrons can be deflected off while the heavier positive ion will be unaffected and can be

measured. Table 3 shows the effect of the magnetic field on the ion currents and amply bears out the theoretical prediction.

TABLE 3.

Accelerating voltage = 2 volts.

Temperature of graphite tube	Current through electromagnet in amps	Negative deflection in mm	Positive deflection in mm
1500°C	0	44	3.5
	1	19	5
	2	12	5
	3	11	5
	5	11	5

The observations clearly show that the negative current largely consists of electrons which are deflected off by the magnetic field and the current falls to about one-fourth of its value after which it is not further affected by the magnetic field. Evidently the remaining part is due to negative ions. The positive current at first slightly increases and thereafter remains constant. In reality the positive ion current is not affected by the magnetic field, the slight increase initially observed is simply due to the fact that some of the very fast electrons which could overcome the retarding potential of 2 volts and reach the Faraday cylinder have now been deflected off by the magnetic field and the positive current therefore increases.

It may be pointed out that the previous investigators have not used a magnetic field to distinguish between the electron and the negative ion current, and have assumed that the negative current is composed entirely of negative ions simply from the fact that the negative current in the blank experiment is comparatively negligible. It will be observed that electrons are produced in the reaction itself (see equations 3 and 4) and therefore the number of electrons produced will be roughly of the same order as the number of ions; hence if during the reaction considerable number of M^+ and I^- ions are produced, the number of electrons will also be appreciable. That this is so is evident from our experimental results which show clearly that the electron current is much greater than in the blank experiment and is approximately of the same order as the other ion currents.

The proper accelerating voltage necessary for the experiment was found out experimentally by trial. Theoretical calculations show that the ions issuing out of the hole have a mean kinetic energy of about 0·3 electron-volts. As quite a large number of ions have velocities much greater than this (in fact they obey Maxwell's distribution law and have all velocities) a retarding voltage of about 5 times this value may be sufficient. Actually in an experiment with lithium iodide the ion currents were measured with different voltages, without magnetic field and the results recorded in Table 4 were obtained,

TABLE 4.

Accelerating or retarding potential in volts	Negative deflection in mm.	Positive deflection in mm.
0·4	17	35
0·5	25	55
0·66	35	98
0·8	41	106
1	59	123
1·33	84	141
1 5	97	150
2	132	180
3	140	194
4	146	204
6	158	224

By plotting the current against voltage it is seen that with increase of voltage there is first a rapid increase in current but in the neighbourhood of 2 volts the increase is very small and regular. The slight increase even after 2 volts may be due to the electric lines of force penetrating the limiting diaphragm whose effect will be to produce a virtual increase in the area of the diaphragm for larger voltages, or it may be due to the stoppage of the fastest ions of the opposite charge or both Evidently the latter effect is desirable but not the former. Hence it is not desirable to increase the voltage beyond 2 volts. For these reasons and partly for the sake of convenience an accelerating potential of 2 volts was used in our experiments. It may be remarked that by taking observations at 2 volts the uncertainty in the measurement of the current is not more than 10% and the resulting error in Q is only about 0·5% while a much larger error is possible due to uncertainties in the value of the vapour pressure as will be seen later.

Hence in our experiments the currents were measured at 2 volts with different magnetic fields and for purposes of calculation the constant values of the negative and positive currents were utilized It is evident from the observations that the magnetic field employed does not affect the ion currents but deflects only the electron current.

The experimental results obtained with RbI and LiI[1] are tabulated below. The salts were supplied by Scherring-Kahlbaum and were extra pure and anhydrous. Care was taken to fill the salts quickly and proceed immediately to evacuate the system since LiI is extremely hygroscopic.

Rubidium Iodide.

Diameter of effusion hole = 1·209 mm.

Distance between effusion hole and limiting diaphragm = 1·8 cm.

Radius of the limiting diaphragm = 0·42 cm.

Accelerating voltage = 2 volts.

Current sensitivity of galvanometer = $1{\cdot}13 \times 10^{-9}$ amp./mm.

[1] Some observations with LiI were already taken by Dr. A. N. Tandon with the older apparatus without the magnetic field device.

TABLE 5.

Temperature of graphite furnace in °C.	Temperature of auxiliary furnace in °K	Vapour pressure of salt in auxiliary furnace in dynes/cm²	Current through electromagnet in amps	Negative deflection in mm.	Positive deflection in mm	$K_2 \times 10^4$ in dynes/cm²	Q in kilocals.
1275	760	1·54	0	108	57	0·430	99·7
			1	60	,,		
			2	53	,,		
			3	52	,,		
			5,6	50	,,		
1300	773	2·60	0	258	97	0·899	99·1
			1	142	,,		
			2	112	,,		
			3	105	,,		
			5,6	102	,,		
1310	774	2·72	0	265	111	0·939	99·6
			1	149	,,		
			2	131	,,		
			3	123	,,		
			5,6	97	,,		
1340	782	3·56	0	240×3	88×3	6·96	95·2
			1	175 ,,	,,		
			2	162 ,,	,,		
			3	155 ,,	,,		
			5	136 ,,	,,		
			6	131 ,,	,,		
			7,8	130×3	,,		
1390	792	5·055	0	235×3	115×3	5·24	99·1
			1	136 ,,	,,		
			2	117 ,,	,,		
			3	111 ,,	,,		
			5	105 ,,	,,		
			6,7	104×3	,,		
1410	797	5·99	0	223×3	104×3	4·11	101·1
			1	136 ,,	,,		
			2	120 ,,	,,		
			3	115 ,,	,,		
			5	109 ,,	,,		
			6	107 ,,	,,		
			7,8	106×3	,,		
1430	799	6·36	0	122×10	52×10	10·2	99·2
			1	277×3	,,		
			2	237 ,,	,,		
			3	212 ,,	,,		
			5	181 ,,	,,		
			6	174 ,,	,,		
			7	168 ,,	,,		
			8	167×3	,,		
1435	807	8·45	0	117×10	58×10	9·8	99·6
			1	74 ,,	,,		
			2	68 ,,	,,		
			3	65 ,,	,,		
			5	58 ,,	,,		
			6	57×10	,,		

Mean $Q = 99{\cdot}1$ Kcal.

Lattice energy $= 99{\cdot}1 + 46{\cdot}4 = 145{\cdot}5$ Kcal.

Electron affinity of iodine $= D + I_M - Q = 76{\cdot}7 + 96{\cdot}0 - 99{\cdot}1 = 73{\cdot}6$ Kcal.

Lithium Iodide.

Accelerating potential = 2 volts.
Diameter of the effusion hole = 1·209 mm.
Distance between effusion hole and limiting diaphragm = 1·8 cm.

TABLE 6.

Temperature of graphite furnace in °C.	Temperature of auxiliary furnace in °K.	Vapour pressure of salt in auxiliary furnace in dynes/cm².	Current through electromagnet in amps.	Negative deflection in mm.	Positive deflection in mm	$K_2 \times 10^7$ in dynes/cm².	Q in kilocals
1350	693	3 54	0	6	27 5	0 5181	130 9
			1	5 5	,,		
			2,3,5	5 5	,,		
1365	696	3 90	0	11	49	1 355	129 0
			1	9	,,		
			2, 3, 5	9	,,		
1385	698	4 14	0	15 5	67	2 711	128 4
			1	14	,,		
			2, 3, 5	14	,,		
1415	702	4 82	0	52	113	7 877	127 2
			1	32	,,		
			2	29·5	,,		
			3	28	,,		
			4, 5	28	,,		
1430	705	5 46	0	40	103	4 720	130 1
			1	26	,,		
			2	24	,,		
			3	22	,,		
			5, 6	21	,,		
1440	707	5 79	0	68	125	9·24	128 6
			1	43	,,		
			2	37	,,		
			3, 4	36	,,		
1470	710	6 45	0	132	180	14 27	129 4
			1	74	,,		
			2	59	,,		
			3	53	,,		
			5	45	,,		
			6, 7	43	,,		

Mean $Q = 129{\cdot}1$ Kcal.

Lattice energy $= 129{\cdot}1 + 38{\cdot}7 = 167\ 8$ Kcal.
Electron affinity of iodine $= D + I_M - Q = 81{\cdot}6 + 123{\cdot}8 - 129{\cdot}1 = 76{\cdot}3$ Kcal.

For calculating K_2 we require the vapour pressure of these salts in the solid state. Unfortunately this is not known. The few available data extend over a narrow region much above the melting point of the salt and cannot be safely extrapolated to temperatures much below the melting point. Even the specific heat data for these salts are not fully known. The only available

course is to calculate the specific heat of the salt by using a Debye term and an Einstein term and then to calculate the vapour pressure of the salt with the help of the following formula.

$$\log p = -\frac{\lambda_0}{4{\cdot}573T} + \frac{7}{2}\log T - \frac{1}{4{\cdot}573}\int_0^T \frac{dT}{T^2}\int_0^T C_{p_s}\,dT - \log\left(1 - e^{-h\nu/kT}\right)$$
$$+36{\cdot}815 + \frac{3}{2}\log M + \log I + 6{\cdot}0056 \quad .. \quad (16)$$

This has been done for RbI by using a single Debye term Calculation by this method gave a value for the vapour pressure differing only by about 15% with the extrapolated value as given by Helmholtz and Mayer In case of LiI, however, there was a large difference possibly due to uncertainties in the value of λ_0 For this reason the extrapolated value of 0 039 mm at the melting point as given by Helmholtz and Mayer was assumed and the following empirical formula was deduced to fit in with this result·

$$\log p \text{ (dynes)} = -\frac{38700}{4{\cdot}573T} + 13{\cdot}4859$$

The vapour pressure p of the salt in the graphite tube is given by $p = p'\sqrt{T/T'}$ where p' is the vapour pressure in the auxiliary tube and T' the temperature of the latter in $^\circ K$. The full Knudsen effect has been assumed here

The dissociation constant K_2 was calculated with the help of the equation

$$K_2 = \frac{2\pi kT}{e^2 S^2}\left(\frac{r^2+d^2}{r^2}\right)^2 \frac{\overset{+}{i}_g\ \overset{-}{i}_g}{p'_{MI}\sqrt{T/T'}}\sqrt{m_{M^+}\,m_{I^-}} \quad .. \quad (17)$$

and the value of Q was obtained from (6) From this the lattice energy $\phi(r_0)$ and the electron affinity were calculated from equations (12) and (11) The data given by Helmholtz and Mayer have been generally utilised, the only exception being in the case of the heat of dissociation of LiI for which the value of 81 6 Kcal has been assumed which represents the mean of the three values 87 4, 82·0, 75·3 given in Landolt and Bornstein tables

Discussion of Results

It will be observed that in the case of LiI the positive current is in general several times larger than the negative ion current which is to be expected since the Li^+ ion being 127/7 times lighter would effuse out $\sqrt{127/7} = 4\ 3$ times faster. The currents will however not be exactly in this ratio since the number of Li^+ and I^- ions inside the graphite tube will not be equal, being to some extent governed by the ionization potential of Li and electron affinity of I and the independent electron concentration (equations 6-9). In the case of RbI the masses of the two ions are not much different hence the two ion currents also do not much differ.

The values of the lattice energy of RbI and LiI and the electron affinity of iodine calculated therefrom are recorded in Table 7, along with the results of

† TABLE 7.

Salt	Lattice energy in kilocal.		Electron affinity of iodine from lattice energy in kilocal.		Electron affinity of iodine by other methods.	
	Theoretical.	By direct experiment	Theoretical	By direct experiment	By G. Glockler and M. Calvin	By P. P Sutton and J. E. Mayer
LiI ..	174·1[1] 176·1[2]	167·8[*]	75·8[1] 73·1[2]	76 3[*]		
NaI .	163·9[1] 164·3[2]	166·4[4]	73 9[1] 73 5[2]	72·0[4]	74 6 ± 1·5	72·4 ± 1·5
KI .. .	150 8[1] 152 4[2]	153·8[3] 150 6[4]	73 2[1] 71 6[2]	70·2[3] 73 4[4]		
RbI .	145·3[1] 148·0[2]	145 5[*]	73 8[1] 71 1[2]	73 6[*]		
CsI	139·1[1] 142·5[2]	141 5[3]	74·2[1] 70 8[2]	71 8[3]		

other workers. It will be seen that the values are in good agreement with other determinations. The mean of our results for the electron affinity of iodine can be put down as 74 9 Kcal. There are various sources of error in the experiment, the chief being the uncertainty in the value of the vapour pressure, the non-uniformity in the temperature of the graphite tube, the error in the determination of temperature by the optical pyrometer, etc. The error due to all these causes is not likely to exceed ± 3 kilocal. in the value of Q and the major portion is due to uncertainty in vapour pressure When the experimental data for vapour pressure in the solid state are known, this uncertainty can be avoided.

We have remarked previously that electrons are present in the negative current and are deflected away by the magnetic field. Thus by subtracting the negative ion current at say 8 amp. through the electromagnet from the total negative current without the magnetic field, the electron current could be known. This point of view was further pursued. From the electron current the partial pressure of electrons inside the furnace was calculated. Again with the help of equation (8) using the value of $E_X = 74$ Kcal and p_I , the partial pressure of iodine atoms inside the furnace was found. Then using (7) we get

† In this table [1] stands for Helmholtz and Mayer (1932), [2] for Huggins (1937), [3] for Mayer (1930), [4] for Tandon (1937) and [*] denotes the values obtained in this paper.

the partial pressure p_M of the alkali atom. Thus knowing the partial pressures of the electron, M atom and M^+ ion the equilibrium constant and the ionization potential of M were calculated The values so obtained for the various quantities in the case of RbI at 1390°C. are as follows $p_e = 1{\cdot}69 \times 10^{-4}$ dynes/cm², $p_{Rb^+} = 5{\cdot}88 \times 10^{-2}$ dynes, $p_{I^-} = 6\ 49 \times 10^{-2}$ dynes, $p_I = 21\ 8$ dynes, $p_{Rb} = 1\ 22$ dynes and $p_{MI} = 7{\cdot}32$ dynes The ionization potential of Rb comes out to be 4 37 volts which agrees very closely with the spectroscopic value Thus our view that a large number of electrons are present in the effusion stream has been completely justified. We have been able to calculate the concentrations or partial pressures of all quantities present inside the furnace and in fact any of the equations 6–9 can be experimentally tested by this method Incidentally it shows that the method is quite suitable for experimentally testing the ionization formula

In conclusion I wish to express my sincere thanks to Prof M N Saha, F R S, for his valuable guidance throughout the work Our thanks are also due to the Royal Society of London for giving a grant which enabled us to construct the furnace and buy its accessories

SUMMARY.

The thermal dissociation of RbI and LiI vapours into their ions has been experimentally investigated in the temperature region 1300–1500°C by an improved apparatus which enables separate measurements of the positive ion, negative ion and electron concentrations From these the equilibrium constant of dissociation at different temperatures is deduced A theoretical formula then enables us to calculate the heat of ionic dissociation of the salt, the values obtained being 99 1 Kcal for RbI and 129 1 Kcal for LiI The lattice energies come out to be 145·5 Kcal for RbI and 167·8 Kcal. for LiI. Using Born cycle we get from these measurements the value of the electron affinity of iodine to be 73·6 and 76·3 Kcal, the mean being 74 9 Kcal These results are in good agreement with deductions from Born and Mayer's theory and other experimental results.

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Eighth Ordinary General Meeting.

The Eighth Ordinary General Meeting of the National Institute of Sciences of India was held in the Library Hall of the Indian Meteorological Department, Poona, on the 25th and 26th July, 1938, from 9 A M to 5 P M with an adjournment from 11 A.M to 3 P.M. on both the days

The following Fellows were present —

Prof M N. Saha, *President*, in the chair.
Principal T S. Wheeler, *Additional Vice-President.*
Prof. S. L. Ajrekar.
Dr. S. K. Banerji.
Mr. T. P. Bhaskara Shastri.
Dr. C. W. B. Normand.
Prof. G. R. Paranjpe.
Dr R P Paranjpye
Dr K R Ramanathan.
Dr. L A. Ramdas.
Prof. S. P. Agharkar, *Honorary Secretary.*

Besides the Fellows there were about 45 visitors present.

The following Fellows had intimated their inability to attend.—

Dr. G. Bose.
Prof. B. K. Singh

1. The minutes of the Third Annual General Meeting were read and confirmed.

2 Dr. C. W. B Normand opened the Symposium on Weather Prediction. The following papers forming part of the Symposium were read and discussed —

(1) Seasonal forecasting in India By Dr. S. R Savur
(2) Franz Baur's forecasts for 10-day periods. By Mr. S Basu
(3) Air mass analysis and short period weather forecasts By Dr S N Sen.
(4) Application of air mass analysis to the problem of forecasting of nor'westers in Bengal By Dr S K. Pramanik.
(5) Upper air data and weather forecasts. By Dr. K. R Ramanathan.
(6) Latent instability in the atmosphere and its consequence. By Dr. N. K. Sur.
(7) Rainfall due to winter disturbances and the associated upper air temperatures over Agra. By Mr. S P Venkiteswaran
(8) Upper air data and weather forecasts. By Dr S. K. Pramanik
(9) Weather forecasting for aviation with special reference to local forecasts. By Mr. P. R. Krishna Rao.
(10) Kinematical methods in weather forecasting. By Dr. S. K. Banerji.

An account of the discussion which followed the reading of the papers is being published together with the papers separately in the *Proceedings*.

With a vote of thanks to the chair the proceedings terminated.

The officers of the Meteorological Department at Poona entertained the Fellows and visitors to tea at 5-15 P.M. on Monday, the 25th July, 1938.

Ninth Ordinary General Meeting.

The Ninth Ordinary General Meeting of the National Institute of Sciences of India was held from 11 A.M. to 12 NOON on Saturday, the 20th August, 1938, in the rooms of the Royal Asiatic Society of Bengal

The following Fellows were present:—

Prof M N. Saha, *President*, in the chair.
Prof. S R Bose
Dr B N Chopra
Dr. Gilbert J. Fowler.
Prof. J. Ghosh.
Prof P N. Ghosh
Dr B S Guha
Dr S. L Hora.
Dr P. Maheswari
Prof. S K. Mitra
Dr. B. Prashad
Dr. H. Srinivasa Rao
Dr. A. C Ukil
Dr A M Heron } *Honorary Secretaries*
Prof S. P. Agharkar }

The Minutes of the Eighth Ordinary General Meeting were read and confirmed.

The following papers were read and discussed —

(1) Notes on Vredenburgite (with Devadite) and on Sitaparite. By Sir Lewis Fermor.
(2) The Rôle of Nitrogen Compounds in the Fermentation of Fruit Juices. By Mr. N. N. Chopra.
(3) A Biochemical Investigation of the tuberculation of water pipes. By Mr. S. C. Pillai.
(4) On the Ionization of the Upper Atmosphere. By Prof. M. N. Saha and Mr. R. N. Rai.
(5) Levi-Civita's Formulæ for two bodies. By Sir S. M. Sulaiman.

With a vote of thanks to the chair the proceedings terminated.

Tenth Ordinary General Meeting.

The Tenth Ordinary General Meeting of the National Institute of Sciences of India was held at Bombay on the 26th and 27th September, 1938. In connection with the general meeting a Symposium on the 'Recent work on the Synthesis of Naturally Occurring Substances' was held and three public lectures were given by scientists

The following fellows were present :—

Prof M. N. Saha, *President*, in the chair.
Dr T S Wheeler, *Additional Vice-President*
Dr N Ahmad
Prof P R Awati
Dr S K Banerji
Prof J. C. Ghosh
Dr P C. Guha
Prof K. G Naik
Dr. C. W. B. Normand
Prof. G. R Paranjpe.
Prof M. Prasad
Dr K R Ramanathan
Prof J N Roy
Lt -Col. S S Sokhey.
Prof S P. Agharkar, *Honorary Secretary*

Besides the Fellows, there were about 60 visitors present.

1. The minutes of the Ninth Ordinary General Meeting were read and confirmed

2. The Chairman announced the names of the following newly elected Ordinary Fellows and Honorary Fellows.—

Ordinary Fellows.

Mr. J. B. Auden.	Prof. S. C Dhar
Dr N. K Bose	Prof R. Gopala Aiyar
Dr. J. K Chowdhury	Mr D. Hendry.
Dr. H Crookshank.	Dr A C Joshi.
Captain S. C. A. Datta.	Dr N. K Sur

Honorary Fellows.

Prof. F O. Bower.	Prof. J Perrin.
Sir Arthur Eddington	Sir John Russell.

Brigadier C. G. Lewis was proposed for election as an Ordinary Fellow of the National Institute under Regulation 12 regarding the election of Ordinary Fellows.

The Symposium was formerly opened by Mr. V. N. Chandavarkar, Vice-Chancellor, Bombay University, in the Sir Cowasji Jehangir Hall, Bombay

University, and the following papers were read in connection with the Symposium in the premises of the Royal Institute of Science:—

1. Some recent developments in the study of the constitution of natural products. By J. N. Ray.
2. History of researches in Organic Chemistry in India. By P. C. Mitter.
3. Synthetic investigations on Bicyclic Terpenes. By P. C. Guha.
4. Synthesis of Coumarins and Chromones. By D. Chakravarti.
5. New Synthetical methods in Coumarin Chemistry. By R. C. Shah and Collaborators.
6. The Structure of Rottlerin. By K. S. Narang, J. N. Ray and B. S. Roy.
7. Synthetical experiments in the Flavone and Isoflavone groups. By K. Venkataraman.
8 The colouring matter of the yellow flowers of *Thevetia Nerifolia* (Apocyanacæ). By R. D. Desai and S. Zafaruddin Ahmad.
9. Attempted synthesis of oroxylin-A, and the Synthesis of Wogonin. By R C. Shah, C. R. Mehta and T. S. Wheeler.
10. Synthesis of some naturally occurring Flavones from Chalkones. By T. S. Wheeler and Collaborators.

The following public lectures were delivered in the Sir C. J. Hall, Bombay University:—

1. How Chemistry can help Indian Industries. By S. S. Bhatnagar.
2. Poisonous Chemicals in Modern Warfare—Anti-gas Defence Measures. By J. C. Ghosh.
3. Geography of Space. By M. N. Saha.

The Fellows were entertained to lunch by the local Fellows on both the days of the meeting. Khan Bahadur Dr. A. K Turner entertained the Fellows to tea on the 27th September, 1938.

Fellows and visitors visited the Department of Chemical Technology of the Royal Institute of Science, Bombay.

The proceedings of the Symposium are being published separately in the *Proceedings*.

With a vote of thanks to the chair the proceedings terminated.

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Symposium on River Physics.

General Introduction.

In pursuance of its general objective, a symposium on the problems of Indian Rivers was organized by the National Institute of Sciences of India during the Silver Jubilee Session of the Indian Science Congress and was held at the Senate House, Calcutta University, at 1-30 P.M. on the 9th January, 1938. The object was to invite the attention of the Government of India and of the Provincial governments to the urgency of investigations carried on proper scientific lines on Indian Rivers

The Presidential Address was confined to a preliminary survey of the problems and emphasized the importance of rivers not only to the agricultural life of India but also to their prospective value as sources of power, which is so important for the industrialization of India. It further emphasized on the action of rivers on the level of cities situated on their banks and drew pointed attention to the destruction of many famous ancient cities like Pataliputra and Gour due to uncontrolled river actions. The case of Calcutta in recent times which is experiencing increasing drainage difficulties was discussed. The importance of starting Hydrological Laboratories with proper equipments was emphasized.

The address of Mr. D. N. Wadia of the Geological Survey of India dealt with the general geological history of rivers of India and with tectonic movements in the crust which have led to widespread changes in the river systems of India within geological times and also in most recent times such as the capture of the Tsampo of Tibet by the Brahmaputra. Dr. S. L. Hora's address was confined to the analysis of river origins from the evidence of river fauna and also supported the theory advanced by the Geological Survey of India regarding river changes in India Mr. G. Lacey dealt with the flow of water in alluvial canals, a problem necessitated from actual experiments on flow of water through canals in the United Provinces and the Punjab. It described the results of the experiments carried out at the Hydrodynamical Laboratory at Roorkee and gave a critical review of the empirical formulæ in use in other countries, formulæ discovered by him, as well as an account of his particular theories. Mr. C. C Inglis, Director of the Hydrodynamical Laboratory at Khadakvasla, Poona, dealt with the subject of hydrodynamical researches by means of models, and their interpretation. Mr. S. C. Majumdar gave a comprehensive survey of the problems of river flow in Bengal. Dr. N. K. Bose gave an account of the work done in foreign hydrodynamic laboratories. The symposium thus represented views on the problem of Indian Rivers from diverse standpoints and is likely to be of great use to the country.

In recent years all countries have awakened to the importance of the problems of water conservancy and control of water resources. The National Resources Committee of the United States Government, the membership of which includes the secretaries for the interior, for work, for agriculture, for commerce and for labour, has recently issued an important document on drainage basin problems and programmes, which has been prepared by the Water Resources Committee with the co-operation of Local, State, Regional and Federated organizations. It is a comprehensive review of suggestions emanating from 45 drainage basin committees, themselves nominated by governments of States and state planning boards including men from interested federal bureaus. The report deals with questions of flood control, irrigation, use of water power, navigation, soil conservation, erosion control, pollution, etc The Indian Rivers present problems which are of as wide variety as their counterparts in the United States. It is, therefore, hoped that the publication of the symposium which the National Institute had organized would focus the attention of the Government of India and the Provincial governments on this very important problem and induce them to adopt the measures advocated by the various speakers.

THE POST-TERTIARY HYDROGRAPHY OF NORTHERN INDIA AND THE CHANGES IN THE COURSES OF ITS RIVERS DURING THE LAST GEOLOGICAL EPOCH.

By D N. WADIA, *M A., B Sc, F G.S, F R G.S., F R A S B.*

(*Read at Symposium, January 9, 1938*)

I. INTRODUCTION.

Few changes in the physical geography of India during early historical times and in the sub-Recent geological age have been so well proved as changes in the river systems of Northern India Following the great geographical revolutions of the late Tertiary ages, the old drainage-lines of Northern India have been radically altered and an entirely new system superimposed The number, volume and direction of the majority of the units of this drainage bear evidences of these changes which in some instances amounted to a complete reversal of the direction of flow of a principal river such as the Ganges

Whether the Deccan was ever an island.

An important question in the investigation of the past hydrography of Northern India is the date of disappearance of the last remnant of the sea from the plains tract of Hindustan proper. Whether, if ever, the Deccan was an island, subsequent to the Eocene, with a coast-line represented by the rocky islands and promontories of Cutch, Rajputana, Delhi, Bundelkhand, Rewa, and Rajmahal, is impossible to decide because the desert sands and river alluvia have completely buried thousands of square miles of rocks along this border since that age The Cretaceous sea of Western India (Bagh epoch), south-west of Rajputana, was only a narrow inlet and probably did not extend as far as Jubbulpore, while the Eocene sea, though spread over a wide expanse of Rajputana, did not go further east than Longitude 74°.

The Eocene sea of Assam was only a surviving gulf of the Cretaceous Arakan sea and was a short-lived feature, being superseded in the early Miocene by the rivers of Assam These two marine inlets—the Bagh sea and the Assam sea—however, had no connection with each other or with the Himalayan Nummulitic sea to the north. There is a strong probability, therefore, that even during the Mesozoic the Deccan was an integral part of the Indian mainland.

The Indo-Gangetic a superimposed drainage.

The drainage pattern of Peninsular India is of very high antiquity and has persisted more or less unchanged since early Gondwana era. On the other hand, the northerly drainage of the Deccan, flowing to the shores of the Tethys in Gondwana times, was completely disorganized in the beginning of

the Tertiary, and subsequently during the late Tertiary and post-Tertiary all its main lines were buried under the 200 miles wide belt of alluvial deposits derived (from the northern highland) from Sind to Manipur. The present valley-system of Northern India, one of the youngest hydrographic systems of the world, has inherited nothing from the old, it being an entirely *superimposed drainage* with no relation whatever to the old river-courses. Only a few vestiges of the deposit of the old Gondwana rivers flowing from the south are preserved in the Salt Range, Kashmir, the Simla hills (? Infra-Krol group), Nepal, Sikkim and Bhutan, in most of which the fortunate occurrence of fossil plant remains of the type of *Gangamopteris* and *Glossopteris* enable a correlation to be established between these isolated extra-Peninsular outcrops and the chains of Gondwana basins in central and south-eastern India, across the Gangetic plains.

The survivors of the Gondwana rivers, after the total submergence of Western Deccan under the lava eruption of the Deccan trap epoch, persisted in their northerly flow probably till the Miocene. This is an assumption plausibly inferred from the occurrence of the wide belt of the conspicuously ferruginous Murree series of deposits in the Punjab sub-Himalayas. On several grounds the Murree sediments are believed to be derived from the Deccan terrane, *i e* from the great iron-bearing Archæan and Purana systems of Rajputana and Baghelkhand, and their ubiquitous laterite cap, rather than from the newly upheaved Himalayas.

II. The Great Prehistoric River of Northern India—the Indobrahm.

The river-changes of Northern India can conveniently be classified into (i) Prehistoric and older, and (ii) Recent and historic. The most notable among the prehistoric rivers of India was a great north-west flowing river—the successor of the Nummulitic gulf which stretched from the head of the Sind gulf to the Punjab and thence along the foot of the embryonic Himalaya chain through Simla and Naini Tal to Assam. As this gulf slowly receded, with the continued uplift of the mountains, it was replaced by the estuary of a mighty river which came into being at this stage and which, since then all through late Tertiary, times, must have carried the combined discharge of the Brahmaputra, the Ganges and the Indus river to the retreating head of the Sind gulf. From this circumstance the river has been named Indobrahm by Sir Edwin Pascoe. G. E. Pilgrim who independently postulated, from his study of the Siwalik system, a river of very much the same description has called it the Siwalik River. The great system of river deposits, designated as the Siwalik system, which is such a remarkable feature of the mid-Tertiary and post-Tertiary geology of Northern India, was built up in the valley-bed and flood-plains of this river. The Siwalik outcrop stretches across the whole breadth of India in a steadily widening ribbon fringing the foot of the Assam, Nepal, Kumaon and Punjab Himalaya and thence southwards constituting the wide piedmont

The river of Pleistocene time.

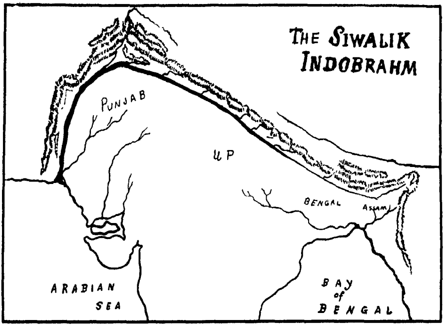

FIG 1.

hills zone of Derajat, Baluchistan and Sind At the end of the Siwalik epoch an uplift of the ground between Hardwar and Bikaner disconnected the

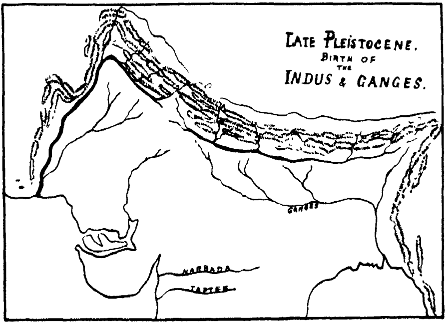

FIG. 2.

Indus system from the Ganges portion of the Indobrahm, thus splitting up that river into two separate drainage basins. The Ganges part, having its outlet blocked to the west, was forced to find an outlet, after reversing its direction, across the now levelled plains to the Bay of Bengal. The Brahmaputra, then a much smaller river, was diverted from its westerly course by a small Bengal river, such as a branch of the Meghna of to-day, which by vigorous head-erosion cut out a passage across the low hilly country connecting the Rajmahal and Garo hills, ultimately succeeded in truncating the Brahmaputra and deflecting its waters along its own channel to the Bay of Bengal. We cannot here enter into the details of these processes of reversal or capture of rivers, nor quote the voluminous evidence for these apparently sweeping statements regarding the ancestry of the three great rivers of Northern India, but the events here related are authenticated and their evidence dealt with at length in the literature cited at the end of this paper.

III RIVER CHANGES DURING HISTORIC TIMES IN THE PUNJAB AND SIND.

The Saraswati river.

There are pointed and persistent references in the Vedas about a large and important river, named Saraswati, flowing through what is at present an arid tract of the Indo-Ganges watershed between the Jumna and Sutlej (the land of Kuru and Sthaneshwar). These references, manifestly based on observed facts by the early Aryans soon after their migration from their Central Asian home, demand a large change in the hydrography of the eastern Punjab at a date so late as the days of Manu. Modern geography can only explain the existence of this river by a westerly deflection of the Jumna, either the entire body or a large part of its waters, and its discharge into the sea either directly, or through the Indus along the now deserted channel of a large river flowing through south-east Punjab and eastern Sind, variously named as the Ghaggar, the Hakra or Sotar. The Jumna, it is probable, must have flowed sometimes into the Ganges and sometimes into the Indus system. The very name Jumna (Yamuna) suggests a river striking out a new course for itself to join a well-known stream and thus acquiring a new name. A well-known parallel example is that of the Brahmaputra, acquiring the name Jumna, while it changed its course suddenly, a century or so ago, to the west of the Madhupur elevation to join the Ganges. Again, the popular tradition among the Hindus that the Saraswati joins the Ganges at Prayag is helpful as suggesting a final eastward oscillation of the channel and breaking away once for all from the Ghaggar.

The Hakra, Sotar, etc., the lost river of the Indian desert.

The second great alteration in Punjab hydrography within the last few centuries, in fact since the XIII century, is the total desiccation of a river which carried a considerable stream of water as late as the XI and XII centuries for a distance of over 600 miles, and which was designated under the varying names of the Hakra, Sotar, Wandan, Wahind. This river flowed from the Himalayas through the eastern Punjab and Sind to the Rann of Cutch, then an inland sea; its southern portion (through Sind) has been identified with the present dry bed of the Eastern Nara of Sind It is now more or less conclusively proved that the Eastern Nara is not the old bed of the Indus deserted owing to the westering tendency of that river On the other hand, historic facts and traditions suggest that the Sutlej was not a tributary of the Indus, but pursued an independent course to the sea in the days before the Mohammedan conquest of the Punjab This is proved by many allusions in the old Greek chronicles (Ptolemy and the historians of Alexander's court) In these chronicles the Biyah (Beas) is the main river referred to as the easternmost tributary of the Indus. It was only at the time of the Arab invasion (XIth Century) that the Sutlej became confluent with the Beas and flowed down the latter's channel, deserting its own bed (the Hakra, Sotar, Wandan, etc.), well-preserved remnants of which for hundreds of miles can still be traced in the sandy plains between Sirsa and Umarkot. The present dry bed of the Eastern Nara from Umarkot downwards, which in the XIth Century was known to be occupied by a large volume of flowing water, is thus no other than the southern portion of this 'lost river' of the Indian desert—the old Sutlej

The Soan Valley—a relic of the Indobrahm.

The Punjab portion of the Indobrahm has disappeared almost completely through the drastic mutilation of its trunk piece by piece. This portion of the Indobrahm, west of the Jumna, was subjected to repeated beheading or truncation by the transverse streams of the southern Punjab, the predecessors of the present Sutlej, Beas, Ravi, Chenab, Jhelum and Indus The only part of the broad but deserted channel that is recognized to-day is the valley occupied by the insignificant stream of the Soan—a river that is obviously a misfit, being out of all harmony with its great basin and the enormous system of alluvial deposits with which its bed is encumbered

All the Punjab rivers have again and again shifted their channels. The Chenab met the Indus at Uch in the XVIth Century, now the confluence takes place at Mithan Kot, 60 miles downstream. Multan was situated on two islands in the Ravi; now the river is 36 miles from Multan. The present union of the Sutlej with the Beas took place only some 200 years ago. In doing so, the Sutlej abandoned a stretch of its bed 600 miles long, leaving it empty and dry for the greater part of the year, thus adding to the desiccation of the eastern and southern Punjab.

The growth of the Thar Desert.

The obliteration of the Sind Gulf by the southward migration of the delta of the Indus, the *Mihran* of the old geographers, is of somewhat higher antiquity. The plains of Sind have since then originated by the sweeping oscillations of the lower Indus, which has wandered over a wide strip of country east of the Kirthar hills. The bed and banks of the Indus (as is the case with all rivers carrying a high proportion of suspended silt) are at a higher level than the surrounding terrain, a feature which greatly aids in the building of wide alluvial plains. Intimately connected with the pulsations of the hydrography of Sind is the growth of the desert of Thar lying between the Aravallis and the Indus basin. This desiccation, due probably to the retreat of the inland sea of Cutch and the withdrawal or deterioration of river-action of the easterly affluents of the Indus, commenced only about 2000 years ago. Chronicles of date before the Christian era, as well as some vestiges of towns buried in the sands, testify to the gradual desiccation of this once fertile country.

IV. Changes in the Rivers of Bengal.

Alterations in the drainage of Bengal are comparatively of a minor nature and of less importance. Southern Bengal has been reclaimed from the sea at a late date in the history of India. The rapid southward advance of the Ganges and Brahmaputra delta, by the enormous amount of silt (daily rate, 960,000 tons by the Ganges and over 100,000,000 tons by the Brahmaputra) poured into the head of the Bay of Bengal is inferable from reliable data James Fergusson has stated that only 5000 years ago the sea washed the Rajmahal hills and that Sylhet was a lagoon of that sea According to him, about 3000 B.C., the time of the advent of the Aryans, the only practically habitable part of the alluvial plains of India was the portion between the Sutlej and the Jumna area drained by the Saraswati and the Markanda. The sea, or rather the tide, was then at or near Rajmahal and a large part of the province of Bengal was a lagoon. This was gradually silted up, and as more land became habitable, the great cities of Aryavarta on the Ganges valley came successively to be established. Hundreds of square miles of the Ganges delta have become fit for man's occupation only since Major Rennell's surveys (*i.e.* 1780–90), as his maps of old Bengal prove. The site of a city like Gour, the ancient capital of Bengal, became desiccated enough to be habitable only about 1000 years ago. Fergusson's dates may not be exactly true, but they are highly suggestive and point to an important principle in the shaping of a land-mass by the interplay of some geographical factors.

Southern Bengal—a lagoon.

The diversion of the Brahmaputra to the east of Madhupur some centuries ago and its later deflection again to the west in the middle of the XIX Century is a well recorded event. This diverted portion which broke away from its course to join the Ganges was named Jumna (Yamuna). Comparatively

minor events are the oscillations of the Ganges and Brahmaputra channels during the last few centuries and the struggle that is going on between them, each tending, by the deposition of its copious silt, to raise its channel and its banks and thus to push the other back. After their fusion, near Goalando, these combined streams (now called the Padma) are depositing their load of silt on the eastern sea-face of the delta, which is changing at a rapid rate by the formation of new ground and new islands, while the western portion of the deltaic coast-line has remained practically unchanged since the surveys of Rennell in the 1770's.

The easterly deviation of the Teesta from the Ganges system to join the Brahmaputra is a still later event, but has considerable significance as indicating the behaviour of streams on alluvially aggraded plains with a level surface.

V. Bibliography.

Important information about changes in the physical geography of India and especially of its river-courses is scattered in the writings of ancient classical authors, *e g* Arrian and Ptolemy (140 A D), and of the Chinese Pilgrims Huen Tsang (VII Century) and Fa Hian The Arab geographers, especially Sulaiman (850 A.D), Ibn Khurdabda, Al Masudi, Al Istakhri (920 A D), Ibn Haukal, Al Idrisi and the compiler Al Kazwini writing about 1263 A.D., also supply material information in their works. These authors' geographical and hydrographical references are mentioned in Professor Dowson's edition of Sir H. Elliott's 'History of India told by its own Historians', 8 vols. (London. Trübner, 1866–1877). More accurate information based on field investigation and research of later date is conveyed in the following papers and monographs

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J Rennell. 1781. An Account of the Ganges and Burrampooter Rivers. *Phil Trans Roy. Soc*, LXXI, p 87.

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CHANGES IN THE DRAINAGE OF INDIA, AS EVIDENCED BY THE DISTRIBUTION OF FRESHWATER FISHES.[1]

By SUNDER LAL HORA, *D.Sc., F.R.S.E., F.N.I., Assistant Superintendent, Zoological Survey of India, Calcutta*

(*Read at Symposium, January 9, 1938*)

CONTENTS

INTRODUCTION.

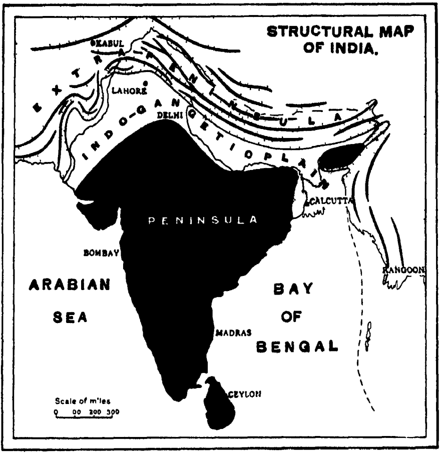
In an earlier article on the 'Geographical Distribution of Indian Freshwater Fishes and its bearing on the Probable Land Connections between India and the Adjacent Countries' (Hora, 1937*a*) attention was directed to the fact that the distribution of the freshwater fishes which are generally restricted to the water courses in which they live constitutes an important criterion for the elucidation of the palæohydrographical features of the main land masses. Evidence was also adduced to show that the present-day freshwater fish-fauna of India is, in the main, derived from the South Chinese and the Indo-Chinese territories and that its spread south-westwards may have been facilitated in the initial stages by the Cretaceous buckling that produced extensive valleys and

[1] Published with permission of the Director, Zoological Survey of India.

later, probably from the Quarternary to the Recent periods, by a series of extensive river-captures (Gregory & Gregory, 1923, Gregory, 1925) in which, as a rule the rivers on the west beheaded the rivers on the east thus transferring bodily the fauna of the latter into that of the former, but not in the reverse direction.

Structure of India.

In studying the geographical distribution of the freshwater fishes of India, both fossil and recent, it is well to bear in mind, that geologically speaking, India proper is composed of three distinct units (text-fig 1) which differ greatly both in their physical features and geological history. The first division comprises the triangular plateau of the Peninsula, including the island of



Text fig 1 —Structural Map of India Diagrammatic.

Ceylon, it has mostly been a land area ever since the Cambrian period. The second division consists of the mountain region which forms the boundary of India on the north-west, the north and the north-east, it is known as extra-Peninsular India. This region was under the sea for the greater part of its

history and became dry land probably during the Tertiary period. The third geological division of India comprises the great Indo-Gangetic Plain which separates the Peninsula from the extra-Peninsular India; it extends from the valley of the Indus in Sind to that of the Brahmaputra in Assam. Its formation is attributed to the orogenic movements that resulted in the uplift of the Himalayas into a mighty mountain range, for it is believed that this area in the pre-Tertiary or early Tertiary periods formed a part of the Peninsula

Drainage of the Peninsula

In view of what is stated above, it is to be expected that the earliest records of the Indian freshwater fishes should be looked for in the region of the Peninsula. Unfortunately in this region the greater part of the palæontological evidence is obscured by the overlying traps (text-fig 2) A certain amount of material is, however, available and this enables us to locate with some confidence one of the earliest drainage channels of India. So far as I am aware, the earliest known fossil-remains of Indian freshwater fishes are found in the Kota-Maleri deposits of the Upper Gondwana period [1] From these rocks three species of the Dipnoan genus *Ceratodus* Agassiz and nine species of the Ganoid fishes of the genera *Lepidotus* Agassiz, *Tetragonolepis* Bronn, and *Dapedius* de le Beche have so far been described. The absence of any type of Teleostei during this period is not a matter for surprise, for it is known that

Fossil Fishes from upper Gondwanas.

> 'None of the bony fishes became large-headed and short bodied until the latter part of the Cretaceous Period, and no sedentary types arose until the Eocene Nearly all the Cretaceous forms are, in fact, still very primitive and generalized even fishes so obviously Chirocentrid as *Portheus*, for example, exhibiting a combination of characters unknown in any one modern family, when the osteology is examined in detail In the obscure interval between the Cretaceous and the Eocene Periods, however, nearly all the modern types of bony fishes originated, and most of these of the early Tertiary formations are only of interest to the geologist on account of their geographical range'. (A S Woodward, 1915)

Both Maleri and Kota are small villages in the valley of the Godavari (text-fig. 2), which contains a very large area of the plant-bearing series of rocks, known as the Gondwana System. According to Blanford (1878), 'Beds of this series extend continuously from about 50 miles south of Nagpur to the neighbourhood of Ellore, a distance of 285 miles. Both Upper and Lower Beds are found in the Valley.' As the greater portion, if not the whole, of the Gondwana system of rocks had accumulated in a great river valley or series

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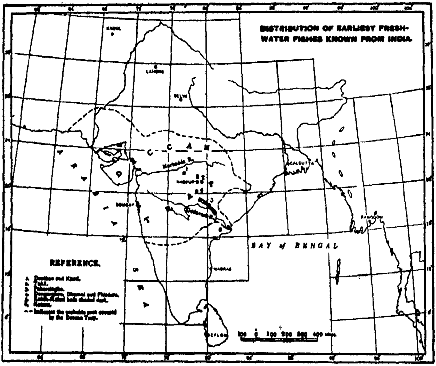
[1] Recently doubts have been expressed regarding the age of these beds. Hitherto they have been regarded as Mid- to Upper-Jurrasic, but Lower Cretaceous affinities have recently been advocated for them.

of river valleys, it is probably safe to assume from the occurrence of the Dipnoan and Ganoid fishes in the Kotah-Maleri beds that a large river of that period flowed in a part of the present valley of the Godavari.



TEXT-FIG 2.—A sketch map of India showing the probable area of Deccan Trap and distribution of Upper Gondwana, infra- and inter-trappean fossil fish-bearing beds of India.

Location of beds marked by Mr H Crookshank and the probable area of the Deccan Trap by Mr D. N. Wadia

From the geological history of the Dipnoan and Ganoid fishes it seems probable that they originated in North Eurasia or North America during the Carboniferous period. Their occurrence in the Kotah-Maleri beds indicates that during the Upper Gondwana period there must have been a land connection between India and the continent of Eurasia to permit the migration into India of the Dipnoan and Ganoid fishes which spread to Australia, Africa and South America about the same period. During the Cretaceous period there were two such connections, one towards the north-east over Assam and Upper Burma and the other towards the north-west over Afghanistan. From a consideration of the distribution of the Lower Gondwana sediments it seems probable that the drainage of the Peninsula was north-westwards and this fact lends great support to the belief in a great mountain tract along the coastal tract of the east coast of the Peninsula. About the drainage of the Permian period Fox (1937, p. 513) remarks as follows:—

'Judging from the distribution of the Lower Gondwana sediments of the Permian period the drainage of this upland region[1] was northward There appears to have been one wide basin trending northwards up the present Godavari valley towards the Satpuras and having an outlet towards Rajputana Another drainage area extended from near Cuttack north-westwards up the Mahanadi valley of today into Rewa where marine beds occur. A third area appears to have been eastwards into Bengal and north-eastwards to the Eastern Himalaya where marine conditions were present.'

The third area, which encompassed within it the Son Valley and the Damuda Valley, the Rajmahal Hills, and the Giridhi coal field, was by far the most extensive and probably received the drainage both from the north and the south (the Bay of Bengal being then a land area). It was probably along the northern tributaries of this basin that the Dipnoan and Ganoid fishes entered India and spread to the valley of the Godavari along the coastal Gondwana basins. There are at present no traces of the drainage of that period from the north, but it has to be remembered that practically the whole of the geological evidence in this region is obscured by the alluvium of the Ganges and the Brahmaputra, and by the uplifted Himalayas and the associated hills.

Fossil Fishes from infra- and inter-trappeans.

According to their age, we have now to consider the freshwater fishes that are found as fossils in the infra- and inter-trappean beds of the Peninsula. These beds were probably laid down in the Eocene period (Hora, 1938), which witnessed a great volcanic outburst; the resultant lava flows covering the greater part of the Peninsula (text-fig. 2). The fish-remains (Hora, in press), mostly fragmentary have been found in the Lametas at Dongargaon, Dhamni and Phisdura, and in the inter-trappeans at Deothan, Kheri, Takli, Paharsingha and Kateru. From the infra-trappean beds two Ganoids, *Lepidosteus* Lacépède and *Pycnodus* Ag., one primitive Serranid, *Eoserranus* Smith Woodward, and *Clupea* Linn., have so far been discovered. From the inter-trappean beds smaller scales of *Lepidosteus* and *Clupea*, a Cyprinoid and a great variety of modern Acanthopterygian fishes have been described (Hora, in press). A careful study of these fossils and the location of the beds leads one to the conclusion that in the pre-trappean period the main features of the land surface had not undergone any very great change since the Upper Gondwana period,—a deep river flowed in the basin of the Lower Godavari and drained north-westwards towards Rajputana. The fact that remains of *Clupea*, are found at Dongargaon and Dhamni shows that the Tethys Sea or an arm of it was not very far from these beds. Even the subsequent flows of lava, that resulted in the formation of the Deccan trap, did

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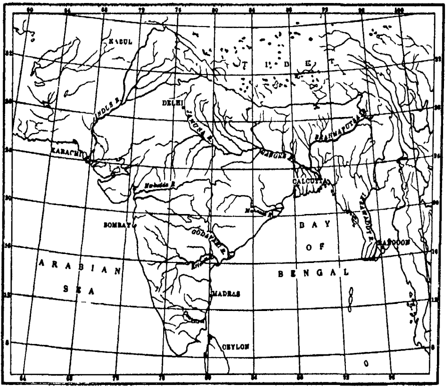
[1] From the northwards working of the ice sheet during the Gondwana ice-age it is believed that the Peninsula of India 'was part of a very elevated country which included what is now the Bay of Bengal' (Fox, *loc. cit.*).

not effect the drainage of the Peninsula [1] to any great extent. From the small size of the *Lepidosteus* scales found at Kateru and Paharsingha, of the *Clupea* scales found at Deothan and Kheri, and from the nature of the Acanthopterygian fishes of the families Polyacanthidæ, Serranidæ, Nandidæ and Pristolepidæ it is safe to assume that after the lava flows the old basin became shallow and that definite estuarine conditions had become established near Deothan and Kheri. This conclusion is also supported by Sahni (1934) from the occurrence of the *Nepadites* palm, a typically estuarine genus, in the inter-trappean



TEXT-FIG. 3.—Present-day drainage map of India.

beds at Chindwara. From the above it is clear that even during the inter-trappean periods the drainage of the Peninsula was towards north-west. The Narbada and Tapti rivers were probably non-existent at that period (Crookshank 1936, pp. 264, 381). The appearance of the new fauna of bony fishes and especially the presence of an Osteoglossid fish, both types having marked

[1] In this connection reference may be made to Fermor and Fox's article on the Deccan trap flows of Linga in which they state as follows:—

'The relief of the surface at the close of the eruption of the first flow would thus tend to be a faint copy of the pre-trappean relief, and denudation acting during a prolonged Inter-trappean interval would accentuate this relief, the tendency being thus for a perpetuation of the pre-trappean drainage lines.'

affinities with the Malayan fauna, in the inter-trappean beds show that the Indian rivers must have had some connection with the drainage channels of the Far East, probably similar to those described above (p 398) during the Upper Gondwana period.

Reversal of drainage of Peninsula.

At what period of the geological history of India this north-westerly drainage of the Peninsula became reversed it is very difficult to say Wadia (1938, p. 388) has directed attention to the wide belt of the conspicuously ferruginous Murree series of deposits in the Punjab sub-Himalayas and concluded that 'The survivors of the Gondwana rivers, after the total submergence of western Deccan under the lava eruption of the Deccan trap epoch, persisted in their northerly flow probably till the Miocene.' It is highly probable, therefore, that the northerly drainage of the Deccan, flowing to the shores of the Tethys in the Gondwana times, became disorganized towards the late Tertiary or post-Tertiary periods. Owing to the present-day pronounced easterly trend of the main channels of the Peninsula and to the exceptional behaviour of the Narbada and Tapti rivers (text-fig. 3) several hypotheses have been put forward to account for these anomalies.

Wadia (1926, p 17), commenting on the present easterly drainage of the Peninsula, draws attention to two main hypotheses:

> 'One supposition regards this fact as an indication that the present Peninsula is the remaining half of a land mass, which had the Ghats very near its centre as its primeval water shed This water-shed has persisted, while a vast extension of the country west of it has been submerged underneath the Arabian Sea. Another view, equally probable, is suggested by the exceptional behaviour of the Narbada and the Tapti These rivers discharge their drainage to the west, while all the chief rivers of the country, from Cape Comorin through the Western Ghats and the Aravallis to the Siwalik hills near Hardwar (a long water-shed of 1700 miles) all run to the east This exceptional circumstance is explained by the supposition that the Narbada and Tapti do not flow in valleys of their own eroding, but have usurped for their channels two fault-planes, or cracks, running parallel with the Vindhyas These faults are said to have originated with the bending or 'sagging' of the northern part of the Peninsula at the time of the upheaval of the Himalayas as described before As an accompaniment of the same disturbance, the Peninsular block, south of the cracks tilted slightly eastwards, causing the eastern drainage of the area '

From what has been stated above regarding the estuarine nature of the fauna and flora of the inter-trappean beds in the Central Provinces, and the probable direction of flow of the post-trappean rivers, it is clear that the first hypothesis cannot be correct, while there would seem to be a certain amount of evidence from different sources in support of the 'tilt' theory. It is known that at Bombay 'There are raised terraces of marine sediments 12 feet above sea level which indicates that large tracts of the western side of the island have been recently elevated from beneath the sea. Submerged forests have been discovered 40 feet below sea level on the eastern shore, thereby affording evidence that the eastern side of the island has been depressed within recent

times' (Fox, 1923). What is applicable to the island of Bombay on a small scale is probably true of the Peninsular block as a whole—an elevation along the west coast and a simultaneous depression along the east coast.

Geologists have reached the conclusion that the straight steep western coast of India is probably a cut-back fault-scarp, 'the hypothetical fault running at some unknown distance out at sea. This fault, if it does occur, must be later in age than the Deccan traps, as they constitute the supposed fault-scarp' (Heron, 1938, p. 129). It is probable that when the land to the west of the hypothetical West Coast fault foundered and became submerged, the present West Coast of India became elevated, thus causing a reversal of the drainage of the Peninsula. It is further supposed that the west coast of India assumed its present form probably in the Pleistocene period Considerable support is also lent to these views from a study of the geology of the sea floor (Sewell, 1937, pp. 23–25).

Attention may here be directed to the uniformity of the sluggish-water fish fauna practically over the whole of the Peninsula. This may have resulted from a reversal of the drainage of the Peninsula as indicated above

River Valleys.

From the nature of their valleys, which are broad and shallow, it is rightly assumed that rivers of the Peninsula are of very great antiquity. We have noticed above (p. 400) that there was practically no change in the position of the main river basins of the Peninsula from the Upper Gondwana period, through the infra-trappean period to the inter-trappean period. During the post-trappean period the Peninsular block may possibly have witnessed the influence of the two types of earth movements, (i) those connected with the uplift of the Himalayas and (ii) those due to the scarp-faulting along the western coast and the general crust-movements of the Pleistocene (Vredenburg, 1906). The former, as noted above (p. 401), may have been responsible for the cracks in the northern part of the Peninsula and produced the valleys of the Narbada and Tapti rivers. Such a thrust-movement from the north would also cause a certain amount of subsidence towards the southern part of the Peninsula. When a movement of this nature is combined with the tilting of the Peninsula from east to west, it becomes easy to postulate the probable changes that might have occurred in the drainage of the Peninsula. The lower portion of the present Godavari river is certainly of great antiquity, as it dates back from at least the Lower Gondwana period while the same cannot be said of its present westerly portion, which during the infra- and inter-trappean period had a more northerly course (text-fig. 2). The present head-water channels of the Godavari would thus be of a much later date, as compared with the age of its lower portion. Probably the same is true of the other rivers of the Peninsula. An hypothesis, like the one advanced above, will also account for the irregularities of the nature of falls in the channels comprising the head-waters of these rivers, for, according to the above supposition, they can only be of a Pleistocene age, the period of the West Coast fault.

DRAINAGE OF THE EXTRA-PENINSULAR INDIA AND OF THE INDO-GANGETIC PLAIN.

The rise of the Himalayas and the consequential orographic changes, which probably commenced during the Eocene period, becoming greatly accentuated during the Miocene with a final phase as late as the Pleistocene, have had a very great influence on the hydrography of India. Some of the probable changes that occurred in the drainage of the Peninsula, as a result of these orogenic movements, have been referred to above, while the main changes in the drainage of the extra-Peninsular India, which are of a comparatively recent date, have been discussed by Wadia (1938). The evidence afforded by the distribution of fishes lends great support to his views, and it may be worth while, therefore, to reiterate in this place some of the main points adduced from the distribution of fishes.

Fossil Fishes from Siwaliks.

It has been mentioned above that by the inter-trappean periods the modern bony fishes had already assumed their dominant position. At the time therefore of the Himalayan uplift, which probably followed the formation of the Deccan trap, we had the modern bony fishes in existence all over India, while, owing to great changes having taken place in the ecology of Indian freshwaters, the Ganoids and Dipnoan fishes had already died out. In the Siwalik deposits are to be found the remains of some of the larger modern bony fishes, such as *Bagarius bagarius* (Ham.), *Mystus aor* (Ham.), *Rita rita* (Ham.) and of the marsh-loving fishes of the family Clariidæ, etc. From these records it seems probable that the members of the Indian fauna characteristic of large sluggish rivers and associated marshes, and with a wide range of distribution in the Oriental region, had already become established in India during the Siwalik period.

Present-day Freshwater Fishes.

The distribution of the present-day Indian freshwater fishes presents the following interesting features, and for their elucidation it is necessary to formulate certain hypotheses regarding the changes in the drainage pattern of India.

(i) The absence of any general similarity between the fish-fauna of the northern and southern faces of the Himalayas.

(ii) The occurrence of the larger forms, such as *Catla catla* (Ham.), *Rita rita* (Ham.), etc., in all the rivers of northern India and their absence from the rivers to the south of the Kistna.

(iii) The increasing poverty of the fish-fauna of the southern face of the Himalayas proceeding from east to west.

(iv) The occurrence of some of the highly specialized torrential forms, such as the Homalopteridæ, in South China, Indo-China, Siam, the Malay Peninsula, Burma, Assam, Bengal up to the Tista valley, and in the hills of the Peninsula.

(v) The formation of local species, very closely allied to Indian forms, in Burma.

(vi) The great similarity between the fish-fauna of the Peninsula and of the Malaya Archipelago.

I have dealt with some of these points in recent papers, but it seems desirable to recapitulate a few of the main arguments here.

Consequent Drainage of Himalayan Rivers.

Though the Himalayas are cut across by rivers, a detailed comparison of the fish-faunas of its northern and southern faces, as explained elsewhere (Hora, 1937*c*), shows that the two faunas are quite distinct, thus indicating that the Himalayas acted as a barrier from the very beginning and that even now when, through erosion, trans- and cis-Himalayan waters have become continuous in places the stupendous gorges in the course of the rivers prevent an admixture of these faunas. Though both the faunas seem to have been derived from southern China, possibly Yunnan, the nature of their components indicates that the northern forms are less specialized and presumably more primitive than the southern forms. The distribution of fishes in Central Asia and in Northern India indicates that with the first movements, that converted the Himalayan region from sea into land, longitudinal basins were produced in its fore-deeps in which the waters flowed from east to west and as the sea receded more and more westwards the freshwater basins extended *pari passu* and permitted the distribution of the Oriental fishes over a wide area. It is on these considerations that I (1937 *d*) favoured the existence of a river of the nature of the 'Indobrahm' of Pascoe (1919) or the 'Siwalik river' of Pilgrim (1919). Such a river in my opinion did not include any portion of the modern Brahmaputra but probably had its headwaters in Southern China.

Indobrahm or Siwalik River.

As has been remarked already (p. 400) up to the Miocene the drainage of the northern part of the Deccan was northwards into the Tethys, and it is probable that a portion of the northern part of the Peninsula may have drained into this Tertiary river, which succeeded the sea in northern India, and thus permitted the distribution of the larger and sluggish-water species of fish from the so-called 'Indobrahm' to the northern area of the Peninsula. Later, when this area 'sagged' and finally was faulted to produce the valleys of the Tapti and the Narbada rivers, the southern tributaries of the 'Indobrahm' had their flow reversed so that they drained into the Mahanadi and the Godavari rivers and thus transferred the fauna of the 'Indobrahm' to the northern rivers of the Deccan. Very little is known of the fish-fauna of the Narbada and Tapti rivers, but from the collections made by the Zoological Survey of India a few years ago in the upper and middle reaches of the Narbada river it seemed evident that this fish-fauna has greater affinities with that of the Ganges and other northern rivers than with that of the rivers of the Peninsula. It is presumably on account of these changes of drainage that the Mahanadi, the Godavari and the Kistna rivers have an Indo-Gangetic element in their faunas, besides the typical Deccan forms. In the Cauveri, however, the characteristic large fishes of the North are totally absent.

Hydrographic Divisions of the Himalayas.

The orogenic movements that influenced the distribution of the brook-inhabiting Himalayan fishes were probably associated with the localized rise of the sub-Himalayas at the boundary between the Assam and the Nepal foothills and in the region of the Potwar Plateau. As a result of the former movement the 'Indobrahm' probably became divided into the Indo-Ganges, which continued to flow in its original channel, and the Brahmaputra of that period, which probably drained a part of Southern China and the area of the Himalayas up to the Tista river, and debouched into the arm of the sea that extended between Assam and Burma in the Miocene and Pliocene periods. Wadia (1938, p 387) has already noted that the Eocene sea of Assam was superseded in the early Miocene period by the rivers of Assam Thus the long prevailing continuous stream of migration of the Far Eastern types of fish along the whole range of the Himalayas became interrupted just beyond the valley of the Tista It seems probable from the records of distribution of certain specialized hill-stream fishes that the Satpura trend of elevated country, which during the Miocene and the later periods stretched diagonally across India to the Himalayas, permitted the dispersal of hill-stream forms, by a series of river captures or through deflection, from the Eastern Himalayas to the western limit of the Satpuras and the Vindhyas, whence subsequent to the elevation of the Western Ghats, the fauna migrated along the Ghats southwards to the hills of the Peninsula. It is presumably along such a route that *Bhavania* Hora (Homalopteridæ), *Silurus* Linn. (Siluridæ), *Parapsilorhynchus* Hora, *Thynnichthys* Bleeker (Cyprinidæ), etc. spread to South India. A recent survey of the fauna of the Rajmahal Hills (Hora, 1938) has lent considerable support to this hypothesis. Recently I (1937*b*, p 10, 1937*f*, p. 336) commented on the remarkable occurrence of the same species of fish, such as *Danio strigillifer* Myers, *Barbus pinnauratus* (Day), etc., in Northern Burma on the one hand and in the hills of the Peninsula on the other. It is easy to understand such a discontinuous distribution when it is remembered that the Brahmaputra is believed to have captured the headwaters of the Chindwin during the post-Himalayan period and thus deflected its fauna towards India not very long ago.

The movement that dismembered the Indoganges into the Indus and the Ganges rivers seems to have occurred not very long ago since the fauna of these rivers has not diverged to any very great extent The dismemberment of this portion of the Indobrahm is usually associated with the rise of the Potwar Plateau (Wadia, 1932) and this rise seems to have hindered the spread of the eastern forms, that had already established themselves as far as the Kumaon Himalayas, to the Punjab Himalayas. The distribution of fishes along the southern face of the Himalayas, therefore, clearly indicates the breaking up of a once continuous westward drainage into three drainage systems, *viz.* a part of the Brahmaputra, the Ganges and the Indus, probably as a result of the last two major upheavals of the Himalayas in the Miocene and the Pleistocene periods.

Isolation of Indian Aquatic Fauna.

Recent detailed work on the freshwater fishes of India and Burma, especially of the hill-streams, has shown that in a number of cases the Burmese examples of a species differ in several important respects from the Indian specimens usually referred to the same species. In this connection reference may be made to the Burmese *Balitora brucei* var. *burmanicus* Hora (Hora, 1932), to the studies of Mukerji (1934) and Hora (1936) on *Crossocheilus latius* (Ham.) and *Labeo dero* (Ham.) and of Hora (1937*i*, 1937*j*) on *Eutropiichthys vacha* (Ham.) and *Clupisoma garua* (Ham.). It has been found that the Burmese fauna is more closely related to that of Siam than it is to that of India. The morphological differences between Indian and Burmese forms lead one to suppose that the two faunas became segregated from each other at not a very remote period, but at the same time isolation seems to have been effected over a sufficiently long time to lead to the production of new species, races or varieties. It seems probable that it was during the Pliocene period that any migration of the Far Eastern forms was rendered impossible by the Himalayas on the north and by the arm of the Bay of Bengal which stretched between Assam and Burma and probably continued beyond the present-day limits of the Himalayas. A large number of species are still common to India and Burma, but for the specialized forms the period of isolation, since the Pliocene, seems to have been sufficiently long to allow the development of new species. Further comparative studies on the Indian and Burmese freshwater fishes are likely to throw considerable light on the hypothesis advanced above.

CONCLUSION.

South Chinese Origin of Indian Fish-fauna.

It is assumed that the fauna of the Oriental Region originated in South China and thence spread mostly to the south, but also towards east and west, and partly to the north and north-west. Unfortunately the fauna of Southern China is not so well known as that of the adjoining territories, but through the activities of Chinese workers several interesting forms have been discovered within recent years. Tchang recorded *Silurus wynaadensis* Day from Lunchow in the Kwangsi Province, but I (1937*g*) found it so different from the Wynaad form that it had to be referred to a distinct species The distribution of the genus *Silurus*, including *Parasilurus* Bleeker, helps in locating its centre of dispersal in South China. Similarly, the distribution of the genera *Pseudecheneis* Blyth, *Parapseudecheneis* Hora and *Propseudecheneis* Hora (Hora, 1937*h*) and of the Cyprinoid genera with a predorsal spine (Hora, 1937*e*) point to the same conclusion. I have given above only such instances as I have studied recently, but several others could be cited in support of this hypothesis.

The distribution of Indian freshwater fishes from the Mesozoic period onwards, taken as a whole, indicates two distinct types of movements in

the continent of Asia, (i) the sinking of the southern and western portions of the main land masses, probably as a result of the foundering of the Gondwana Continent, so that the north-eastern waters drained towards the south-west, and (ii) the rise of the central portion of the main land mass, somewhere in Southern China, which permitted the dispersal of the aquatic fauna of this region in all directions. The close similarity of the faunas of the Peninsula of India with that of the Malay Peninsula is thus due to the simultaneous migration of the primitive forms in these remote corners from a common ancestral stock and not to any exchange of faunas *inter se*. The same argument also applies to the occurrence of similar forms, such as *Silurus*, *Barbus*, etc., in Europe and in Southern Asia.

Similarity of Peninsular and Malayan Faunas.

Historic changes in the drainage of India, such as the disappearance of the great river Saraswati of the Vedic period, the deflection of the Jumna from being a tributary of the Sutlej to its now being a tributary of the Ganges, the independent course of the Sutlej to the sea, etc. etc., have left no impress on the distribution of fishes, for the entire area in which changes have occurred during the historic times contains a uniform fauna of Indo-Gangetic fishes.

Recent Changes.

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SUMMARY.

Attention is directed to the fact that freshwater fishes constitute an important group for the elucidation of palæohydrographical problems. The geological structure of India is briefly described and from the occurrence of the Dipnoan and Ganoid fishes in the Kota-Maleri beds of the Upper Gondwana period the position of one of the main drainage channels of the Mesozoic period is indicated. From the location of the infra- and inter-trappean beds containing fish-remains it is pointed out that the main drainage of the Peninsula did not undergo any change after the Upper Gondwanas and during the formation of the Deccan traps. From the occurrence of estuarine fishes in the various infra- and inter-trappean beds of the Central Provinces it is concluded that the drainage of the Peninsula was towards the north-west. Evidence is adduced from various sources to show that there was a reversal of the drainage in the post-trappean period. From the nature of the valleys of the Peninsular rivers and from certain other features of the physiography of the Peninsula

it is concluded that the present-day lower portions of the rivers are of great antiquity whereas the upper reaches are of a comparatively recent age.

In considering the changes in the drainage of extra-Peninsular India and the Indo-Gangetic Plain, attention is directed to the fact that before the time of the formation of these regions modern bony fishes had already become the dominant group and among the Siwalik rocks remains of some of our present-day species are entombed. Some salient features of the distribution of Indian freshwater fishes are enumerated, and a number of hypotheses to account for the known facts of distribution are advanced. It is indicated that the young Himalayas had a consequent drainage and that their deep gorges are a secondary feature. Evidence is adduced in support of the great Tertiary river of Pilgrim and Pascoe and it is shown how through two localized upheavals of the Himalayan foothills at different periods this mighty river became dismembered into three hydrographic divisions, the Brahmaputra, the Ganges and the Indus. Attention is directed to the differences between the fish-faunas of India and Burma, and it is supposed that some form of isolation must have been responsible for the divergence in these faunas.

In conclusion attention is directed to the origin of the Indian freshwater fish-fauna from South Chinese sources, and an explanation for the similarity between the fish-fauna of the Peninsula and the Malay region is given.

Some of the authenticated historic changes in the course of certain rivers of the Indo-Gangetic Plain are briefly referred to, and it is pointed out that they are too recent to have left any impression on the distribution of fishes, especially of the Indo-Gangetic region which has a uniform fauna over a very wide area.

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THE FLOW OF WATER IN ALLUVIAL CHANNELS.

By GERALD LACEY, *B.Sc.* (*Engg. Lond.*), *M.Inst.C.E.*

(*Read at Symposium, January 9, 1938.*)

The author desires to preface his paper on alluvial flow with his congratulations to the Indian Science Congress on the auspicious occasion of its Silver Jubilee, and to express his appreciation of the most welcome invitation extended to him to take part in the Symposium on River Physics.

The study of the behaviour of Indian rivers by the engineering profession dates from the inception of large irrigation works in this country nearly a century ago. In the United Provinces and the Punjab, snow-fed rivers were tapped at the point of debouchment from the hills, and the difficulty with which the engineers were faced, viz., the construction of works in an alluvial boulder river bed, presented special problems in respect of river training which yet await a final solution. In Madras where the headworks were constructed in fine alluvial rivers the major problem was the construction of a permanent weir on a shifting sandy bed. Associated with these problems was the necessity for constructing irrigation canals transporting alluvium, withdrawn from the rivers, which would achieve a working stability, and neither silt nor scour.

With the growth of communications and the need for bridges, both for roads and railways, the adoption of the system of sinking wells as a foundation for bridge piers led to an immediate study of the subject of scour. Coupled with this first consideration of secure pier foundations was the necessity for assessing the correct flood width of an alluvial river subject to the wildest vagaries, and the need for river training works to secure that the river obeyed the behest of the engineer.

It was not however until 1903 that Sir Francis Spring in his classic work '*River Training and Control*' co-ordinated the labours of previous workers with his own great knowledge of the subject, and thus laid the foundation of the modern empiric study of river control in India.

On canals the difficulty of designing channels transporting alluvium, and of assessing water surface slopes, was removed to some extent when Bazin published his first formula, and to a greater degree when the Kutter equation was adopted. An ever-present trouble, however, was the removal of the fine alluvium or 'silt' from the branches and distributaries of irrigation systems. It was in 1895 that Kennedy produced his empirical equation connecting the mean velocity of a silt-transporting channel with its critical non-scouring and non-silting depth, and thus became the pioneer of modern irrigation research.

It has been only of more recent years, as the importance of model experiments came to be realized, that some attempt has been made to envisage the

problem of flow in alluvial channels as a whole. The full significance of Osborne Reynold's invaluable work on tidal models in 1888, models in which not only tidal phenomena but also scour and fill were faithfully reproduced, long remained unrecognized.

There is now, however, a realization of the value of model experiments, and a growing recognition of the fact that the gap between the laboratory model and the river prototype is filled to a marked degree by the great mass of channels of all sizes in the great irrigation systems of India, each flowing in its own bed of previously transported alluvium, and each transporting its own silt charge. The necessity for exaggeration in the vertical scale of models, so frequently ascribed by the laboratory worker to the need for silt movement and of avoiding laminar viscous flow, arises from a phenomenon which is faithfully reproduced in *all* channels, large and small. Thus the small minor distributary with its rapid slope is a model of the branch with its less severe gradient, and the branch in turn is a model of the main canal.

The significance of this feature of alluvial channels is that with exaggeration in the vertical scale there is an invaluable diminution in the time scale, and our knowledge of the behaviour of large alluvial rivers can be rapidly supplemented by information gleaned from a field of smaller scale. There is thus a swing from the old system in which the laboratory worker was divorced from his essential background, and the practical engineer was left to his own resources. The early study of river *behaviour*, unaccompanied by mathematical analysis, could be said to be one of river psychology rather than physics.

The isolated fields of different workers are now merging into one broad plain, covering the entire subject of flow in alluvium from the smallest laboratory experiment to the largest river, and the knowledge of the laboratory worker is now re-inforced not merely by the understanding and experience of life-workers in the larger field, but by the presentation of a mass of invaluable data now made available from the alluvial canal systems of India.

The science of river physics therefore, in the broad and comprehensive sense in which the author understands the term, is one of modern growth and no more fitting venue for a symposium on the physics of rivers could be found than modern India.

Fortunately for the irrigation engineer, the alluvial channels with which he is concerned flow for the greater part with a uniform discharge, the only wide exceptions to this rule are the rivers from which he draws his supplies and the escapes which relieve the canal systems of surplus supplies during emergencies or sudden cessations in demand.

In a regime alluvial channel not only is the flow uniform, but there is an assumed constancy in every dimension, and in the grade of silt transported. In practice none of these *desiderata* is perfectly achieved, but uniform flow is nevertheless the basis of most of our present knowledge of alluvial river physics.

In this paper the author essays a review of recent developments in India in the theory of regime flow, and applies such theory to the solution of certain

river problems. In making his analysis the author regards the hydraulic mean depth as a fundamental variable, and, considering the cross section from a hydraulic, as opposed to a geometrical view-point, treats the hydraulic mean depth as elevated vertically on the developed horizontal wetted perimeter. In the previous regime analysis of Kennedy the vertical depth 'D' was measured over the horizontal bed of the channel and correlated with the 'critical velocity': in the author's treatment of the subject,[1] presented in two recent papers to the Institution of Civil Engineers, the hydraulic mean depth was selected by him as fundamental and this 'rehabilitation' of the hydraulic mean depth as a variable was the author's first contribution in this field

Dealing with the subject historically the elementary flow formula is that of Chezy

$$V = C\sqrt{RS} \qquad (1)$$

Experience has shown that this expression is incorrect, and that for accuracy it should be replaced by the somewhat complicated Kutter equation, or preferably by its simple exponential equivalent the Manning formula

$$V = K R^{1/6} \sqrt{RS} \qquad (2)$$

The critical velocity equation of Kennedy can be written

$$V = m D^{.64} \qquad (3)$$

and it is this empirical expression denoting a non-scouring, non-silting velocity, and an effective dynamic balance, which is the foundation of all later work on the subject of regime in alluvium.

For a channel to be in Kennedy regime it is necessary for both equations (2) and (3) to be satisfied: in design the ratio of B the bed-width to D the depth was determined empirically. The fact that the vertical depth appears in one relationship and the hydraulic mean depth in the other makes mathematical treatment difficult.

In 1926 the author found on plotting the mean velocity of the Kennedy data against R, the hydraulic mean depth, as computed from the dimensions of Kennedy's channels, that the mean velocity varied directly as the square root of the hydraulic mean depth. This simple relationship was confirmed by a later plotting of regime data obtained from Madras.

The author's equation may be written

$$V = k R^{1/2} \qquad (4)$$

in which the constant k characterizes the silt grade.

It is of interest to note that when the author first published this equation it was severely criticized by a reputable engineering journal in India on the grounds that it was a 'backward step to Chezy'.

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[1] 'Stable Channels in Alluvium', 1930.
'Uniform Flow in Alluvial Rivers and Canals', 1934.

The new relationship shows that in all regime channels of the same silt grade the Froude number V^2/gR is a constant: a fact of importance when dimensionless arguments are employed.

If equation (4) is combined with the Manning equation the slope should vary inversely as the cube root of the hydraulic mean depth, a conclusion that subsequent analysis of regime data has failed to confirm. In alluvial channels it will be seen that the correct type of formula should be

$$V = K' R^{\frac{1}{4}} \sqrt{RS} \qquad \ldots \qquad \ldots (2a)$$

It is evident that a use of equation (4) combined either with equation (2) or (2a) is not sufficient to determine the dimensions of a channel: the ratio of the wetted perimeter P to the hydraulic mean depth R must either be assumed, or a mathematical expression found for the shape P/R.

In 1919, Lindley in the Punjab published a valuable collection of data which included the slope S, and the hydraulic mean depth, but omitted the mean velocity. A statistical analysis of this data by the author in 1930 led to the equation

$$R^{\frac{1}{2}} S = k' \qquad \ldots \qquad \ldots \qquad \ldots (5)$$

In this expression, also, k' characterizes the silt grade A little reflection shows that this equation coupled with equation (4) must lead to a modified Chezy equation of the type (2a).

It follows from equations (4) and (5) that in all regime channels of the same silt grade

$$V \propto R^{\frac{1}{2}} \propto 1/S \qquad \ldots \qquad \ldots \qquad \ldots (6)$$

a relationship of remarkable simplicity. In terms that a canal engineer will understand this expression means that if in a main canal the slope is 8″ per mile and the mean velocity three feet per second, then in a small offtaking minor carrying the same silt grade, with a mean velocity of one foot per second, the slope required is two feet per mile It is somewhat paradoxical to say that the mean velocity varies inversely as the slope but the statement is nevertheless a fact.

It is of interest to consider whether from equation (6), and without reference to data involving the wetted perimeter, it is possible to obtain an equation in terms of Q the discharge. The author in 1930 solved this problem in the following manner. The exaggeration in the vertical scale of a model as compared with its prototype is exhibited in the enhanced water surface slope: the vertical scale which assigns the hydraulic gradient is from the hydraulic viewpoint R: the horizontal scale, hydraulic, both lateral and longitudinal, is the wetted perimeter P: hence the slopes vary as R/P. Thus

$$R/P \propto S \propto 1/V \qquad \ldots \qquad \ldots (7)$$

$$\text{and} \quad P \propto RV \propto Q^{\frac{1}{2}} \qquad \ldots \qquad \ldots (8)$$

The accuracy of this assumption depends on the degree of approximation of the mean depth to the hydraulic mean depth, and of the wetted perimeter

to the water surface width; in channels of any size the difference is negligible and in rivers is not perceptible.

Direct plotting of wetted perimeter data against the discharge by the author in 1928, and recent statistical analysis of data, both in Sind and the Punjab, have shown conclusively that the equation

$$P = 2\ 67\ Q^{\frac{1}{2}} \qquad . \qquad . \qquad (8a)$$

is correct Since the introduction of the silt grade as a variable has failed to effect any improvement in this relationship, there is a fair amount of evidence to show that it is independent of silt grade, and characteristic of all alluvial channels transporting water.

From equation (7) the formulas

$$Q \propto V^6 \qquad .. \qquad . \qquad .. \quad (9)$$

$$\text{and} \quad S \propto 1/Q^{\frac{1}{6}} \qquad . \qquad .. \qquad . \ (10)$$

are readily derived

Elimination of the silt characteristics in equations (4) and (5) leads finally to the equation

$$V = 16\ R^{\frac{2}{3}}S^{\frac{1}{3}} \qquad . \qquad .. \ (11)$$

in which the rugosity or silt grade is implicit in the slope and depth the channel adopts

Equations (4) and (8a) are fundamental to the solution of model problems.

It may well be asked what application these equations can have to river physics; the simplest possibly is in the design of tidal models.

Equation (4) is of the same form as the familiar equation for the velocity of wave propagation: equation (8a) is new and has not hitherto been applied to tidal problems.

If by 't' is understood the tidal period of the model, and by 'T' the period of the prototype, the necessary scales are, according to the author, as follows —

Vertical	.	..	t/T
Horizontal	.	..	$(t/T)^{\frac{4}{3}}$
Exaggeration	..	..	$(T/t)^{\frac{1}{3}}$

In current practice the principles of Osborne Reynolds are applied, and consistent with the correct reproduction of tides, the vertical scales of models have been exaggerated in an arbitrary manner. The equations show that exaggeration *must* diminish with an increase in size, and that to build a model to a very large scale and thereafter to exaggerate the scale unduly is to depart from accuracy Effectively tidal phenomena can be reproduced, by the old method, but erosive and silting effects are not so correctly represented.

The same principles apply to all river model experiments designed to predict river behaviour. It is thus necessary to secure firstly that in the model and prototype the same Froude number obtains, and secondly, that in model and prototype the wetted perimeter varies as the square root of the discharge.

These principles have been applied with success, at the hydro-dynamic research station at Poona, to the solution of problems connected with the Hardinge Bridge over the Ganges at Sara. Reference will be found to the author's equations in a recent Vernon Harcourt lecture delivered by Professor Gibson to the Institution of Civil Engineers, and, so far as the author is aware, these formulæ represent the first attempt to place exaggeration in the vertical scale on a rational basis. In Nature it is seldom that all the dimensions are equally free to vary and the value of the wetted perimeter assigned by equation (8a) is therefore termed by the author the minimum stable width. In river model work it is, however, sufficient to secure that the shape, the ratio P/R, bears the same ratio to the velocity as in the prototype.

Equation (8a) has an immediate practical application to the problem of flood scour at a bridge site, once the silt grade is known. Not only can the maximum scour for a given maximum discharge be computed, but also the required minimum waterway. Thus if an alluvial river has a maximum flood discharge of one million cusecs the minimum waterway which the river could adopt in Nature would be 2,670′ or approximately one half mile. The Mississippi in a straight reach below Fort Jackson, and near the delta, is subject to a cycle of flood discharges not far removed from one million cusecs and the width is almost exactly 2,650 feet.

In the Punjab, and in Sind, small alluvial channels subject to a steady discharge faithfully reflect the same characteristic, channels with a discharge of one hundred cusecs demanding a wetted perimeter of approximately 27 feet.

The use to which regime equations can be put in solving river problems must always depend on the extent to which the variables are as a fact free to vary. In theory silt grade and discharge uniquely determine the dimensions of a channel; in practice this is seldom the case.

In the boulder region at the foothills the great floods, during which the rivers may truly be said to be alive, are of short duration and occur at rare intervals. It would thus be incorrect to employ equation (10) in an attempt to associate the discharge with the slope The general ground slope, which is sensibly the hydraulic gradient, is a dominating factor. The river in flood may merely dissipate its surplus energy by scour and thus increase its hydraulic mean depth. In such a case equation (11) would apply. Alternatively, such a river might scour until the increased size of boulders encountered forced the river to widen and attack less coarse material. Very frequently in boulder rivers the surplus energy is destroyed by the basic flood discharge Q which would demand a slope S, disintegrating into a number of sub-discharges separated by shoals and islands. These sub-discharges might each eventually demand a slope assigned by equation (10). This process, which can be called 'interweaving', leads to a greater slope, and owing to the lack of equality in the sub-discharges, to a 'warped' flood plane. It may sometimes occur in the boulder region that all the scattered discharge threads are united at one

site presenting one well-defined flood 'thalweg'. In such a case, provided that the banks are erodible and that there is no 'gorge', equation (8a) would apply.

The process by which surplus energy during floods is absorbed is also associated with the phenomenon of 'meandering' or, as it is sometimes termed, 'tortuosity'. The author would define 'tortuosity' as an irregular course imposed on a river by the terrain through which it flows, and 'meandering' as a course which is inherent in the material transported and the range of discharges encountered. For meandering to occur there must also be a wide alluvial plain of material identical with that transported.

Rivers in the hills, prior to entering the plains, follow a tortuous course 'interweaving' is a form of tortuosity imposed by the general ground slope of the terrain, the other variables being free to vary. 'Meandering' is set up in the true alluvial plain which has been built up by ceaseless vagaries in the past. The root cause of meandering is the fact that the great floods demand a smaller slope, and are free to dissipate their surplus energy by a lengthening of the course of the river and an equivalent reduction in gradient In the course of the river from the foothills where the slopes are severe, to the sea where the slope is zero, there is perpetual activity. Not only is the alluvial plain slowly built up, but in the process there is ceaseless selection and rejection by the river of alluvium previously transported. As is inevitable the finer materials demand lesser slopes and are transported furthest, this in itself would explain the progressive reduction in silt grade as a river approaches the sea. There is also the process of slow silt attrition in the river bed, but the author considers this a secondary rather than a primary cause, apart from active attrition during floods in the hills, much of the finer silt must be ascribed to soil washings and soil disintegration unconnected with dynamic river action.

The relation between the basic ratio characterizing silt grade, V^2/R, and the average size of the silt particles is not as yet finally determined. In 1930 the author suggested the empirical relation $V^2/R \propto d^{\frac{1}{2}}$. An intensive study of regime alluvial channels coupled with silt analysis has been recently initiated by the Irrigation Research Institute, Lahore, and this among other relationships is under examination.

It has not been possible in this brief paper to do more than draw attention to those elementary principles which the author trusts may serve to clarify issues, and to restrict generalization in river physics

From the author's study of the subject he holds, despite the complexity of the problem presented by our great Indian rivers, that the basic equations are of great simplicity, and that it is on the foundation of the 'normal' or 'regime' channel flowing with constant discharge and silt charge, that our ultimate knowledge of river physics must be based.

Recent work on the flow of water in pipes, of varying degrees of geometrical roughness, has brought this strictly limited branch of hydraulics to a stage approaching finality; it would, however, be a grave mistake to attempt

to apply equations derived from such a source to open channel flow. The fact that in alluvial channels the boundary is far from rigid, and that the bed itself is moving forward, must set up an entirely different distribution of velocities within the cross section.

In the author's opinion, based on his experience, the normal cross section of a regime channel in incoherent alluvium closely approximates to a semi-ellipse, of which the water surface coincides with the major axis. In such a channel the forces generating the section are at all points normal to the wetted perimeter. It is possible therefore to conceive a semi-elliptical cross section in which the 'isotachs' or velocity contours are confocal, and the orthogonals represent the lines on which the forces act. The method of analysis would be similar to that adopted by Prandtl: the formulas obtained should, however, be very different, and it is hoped not far removed from those the author, has quoted in this paper.

THE USE OF MODELS FOR ELUCIDATING FLOW PROBLEMS BASED ON EXPERIENCE GAINED IN CARRYING OUT MODEL EXPERIMENTS AT THE HYDRODYNAMIC RESEARCH STATION, POONA.

By C. C. INGLIS, *C.I.E., M.Inst.C.E.*

(*Read at Symposium, January 9, 1938.*)

1. Of recent years so many claims have been made regarding the successful application of model research to the solution of hydraulic problems that the public are now under the impression that any engineering problem can be simply solved by the use of models. A corrective to this view was provided when Herbert D. Vogel, Director of the U.S. Waterways Experimental Station at Vicksburg, in replying to the discussion on his Paper entitled 'Hydraulic Laboratory results and their application in nature' published in the December 1935 issue of the *Proceedings of the American Society of Civil Engineers*, wrote:—

> 'In an effort to find proof—or disproof—of the reliability of open channel experimentation, this paper was tossed out as a challenge. The results, while disappointing, were nevertheless illuminating in their paucity, and the question could now be asked, "Are current studies being undertaken (1) because of the proved validity of the method, (2) because models are a cheap means of approximation, or (3) simply because it is fashionable to carry on "scientific" research?" To run down the answer to this query, circular letters were sent out from the U.S. Waterways Experiment Station during August, 1934, to more than fifty laboratories or individuals engaged in hydraulic research. It was requested in each case that information be furnished regarding the performance of any model tests, the results of which had been substantiated subsequently by results obtained in the field. Twenty of these letters were directed to addresses within the United States and the remainder were sent to foreign countries.
>
> 'Replies were received from twenty-eight of those addressed, twelve of these being from laboratories within the United States. With a few notable exceptions, the replies contributed scarcely any information directly pertinent to the subject.'

Nearly all the cases cited were of models with rigid boundaries, several of which gave only approximate correlation, and 'little or no information was received in justification of movable bed models'.

2. The object of this paper is to show —

(i) that there are eight markedly different types of models, only one of which presents little difficulty and gives results suitable for immediate application, whereas other types, especially those relating to flow in rivers, present great practical difficulties;

(ii) that much larger models than have generally been used in hydraulic laboratories in the past are required to give accurate results, especially in the case of erodible models;

(iii) that most flow problems—even investigations into the movement of silt—which have hitherto generally been investigated in laboratories in parallel sided flumes, as though they were 2-dimensional questions, are essentially 3-dimensional problems, and

(iv) that model experiments are a very valuable aid in the solution of practical engineering problems, but that success with them depends mainly on engineering skill which they cannot replace.

3. Model experiments may be divided into 8 main types:—

Types of models.—

I. *Models which are geometrically similar in shape to the prototype and give geometrically similar results*

II. *Models which are geometrically similar in shape; but do not give geometrically similar results*

III. *Regime models* in which conditions of flow are maintained constant, with complete freedom as regards silting and scouring.

IV. *Combined open channel and rigid models*

V. *Rigid and semi-rigid vertically-exaggerated models* in which conditions are imposed, e g *tidal models*

VI. *Models with mobile protection*—falling aprons, spurs, protection round piers, etc

VII *Meandering river models.*

VIII. *Combined rigid, mobile and meandering river models.*

4. Before describing examples of the various types of models, it may be explained that the main difficulty in the use of models is due to dynamic similarity requiring the same Reynold's number $\frac{VR}{\nu}$ in model and prototype to obtain similarity of viscous effects, and the same Froude number (V^2/gR) to give similarity of gravity effects, where V = velocity, R = hydraulic mean depth and ν = kinematic viscosity To avoid this difficulty, it has been customary to design according to whichever effect was the dominant factor, either ignoring the other, or allowing for it on the basis of scale effect. The effect of scale has been analyzed in great detail in connection with ship design, but has not been investigated with similar thoroughness in other directions.

Until recently, it was customary to assume that provided the Reynold's number exceeded about 2,500 its effect was almost negligible; but there is now ample evidence to show that much higher values of Reynold's number are required in a model.

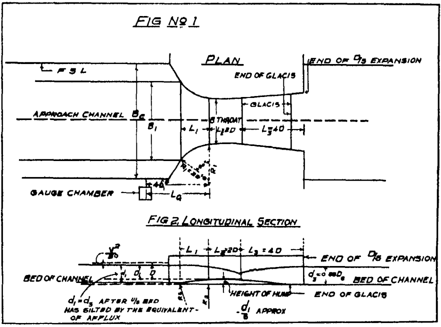
5. To return now to the description of various types of models.—

I. Models which are geometrically similar in shape and give geometrically similar results.

Two examples are given below of models of this type —

(1) Crump type 'standing wave flume', and (2) Gibb module

6. (1) A 'standing wave flume' is a device for measuring discharges. It consists (see figures 1 and 2) of a bell-mouth entrance, a throat, and, where



it is desirable to dissipate energy or to recover head, an expansion downstream, in which a standing wave forms, leading to recovery of 'head'

The feature of the standing wave flume designed by Mr E. S. Crump (Superintending Engineer, Punjab Public Works Department) is that its throat, which has a horizontal sill throughout its length, is made sufficiently long (= twice the upstream depth of water over the sill) to insure that the 'control section' is contained in the throat section As a result, the discharge varies according to $D^{1.5}$, where D = total energy head above sill of flume = depth of water upstream over sill plus head due to velocity of approach (or D_1+h_v).

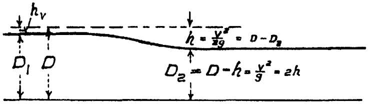
The theory of the Standing Wave Flume is that the maximum discharge occurs when the velocity of flow in the throat, $\overline{V}_2$ = the 'critical velocity'

$$= \sqrt{\frac{gA_2}{B}},$$

where A_2 = area of flow in the throat and B = breadth of water surface in the throat. Under these conditions the energy of flow is a minimum. In the Crump type flume the sides of the throat are vertical and $\overline{V}_2 = \sqrt{g\,D_2}$.

In horizontal flow, with vertical sides—

FIG: 3



$q = D_2\sqrt{2gh}$, where q = discharge per ft width of flume and
D_2 = depth in throat

$= \sqrt{2g}\,(D-h)h^{1/2}$

$= \sqrt{2g}\,(D\,h^{1/2} - h^{3/2})$

where h = head causing velocity.

So q will be a maximum when

$$\frac{d_q}{d_h} = 0 = \sqrt{2g}(1/2D\,h^{-1/2} - 3/2h^{1/2})$$

or when $D = 3h$ and $h = D/3$ and as $D_2 = D-h$,

$D_2 = 2h$ or $2/3D$

and the discharge $= D_2\,V_2$

$= 2/3\,D\sqrt{2g \times D/3}$

$= 3{\cdot}088\,D^{3/2}$ . . . . (1)

Although flow conditions in Mr Crump's design follow theory so closely that the error in the exponent is negligible, yet even in this case, there is some 'scale effect' in small models, due to it being impossible to make the boundary conditions similar to those in the prototype; but this difficulty can be eliminated by using large models.

'Head' can be recovered by a standing wave (in a flume constructed downstream with diverging sides). In this part of the model, geometrically similarity of flow is less fully attained, and so considerably more head can be recovered in large than small flumes—the modular limit (the maximum value of D_3/D_1 for a particular discharge which just does not raise the upstream water level) being as high as 92 per cent in large flumes with Q greater than 1,000 cusecs but only 85 per cent in a one cusec flume. This does not affect the accuracy of the flume as a measuring device; but merely lowers the 'modular limit', and hence the maximum downstream water level which just does not cause afflux—i.e. a rise in upstream water level.

The reason why this model gave geometrically similar discharges was because—

(a) the length of the throat was sufficient to contain the control section and insure similar flow conditions, and

(b) the model was sufficiently large to make it possible to have boundary conditions similar to those in the prototype.

7. (ii) *Gibb module*:

A module is a device for maintaining a constant discharge, irrespective of the upstream and downstream water levels within the working range. Figures 4 and 5 show plan and section of a Gibb module.

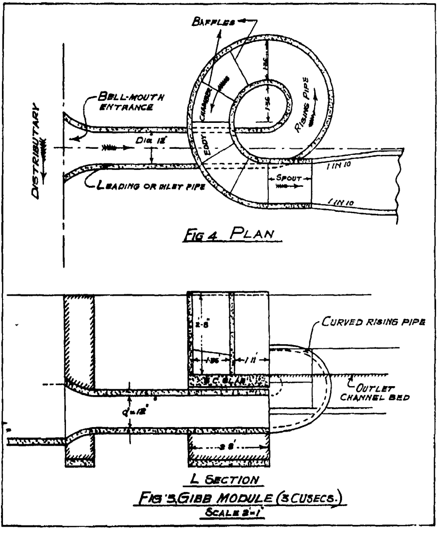


FIG 4 PLAN

FIG 5 GIBB MODULE (3 CUSECS.)
SCALE 2"=1'

It consists of an upstream pipe which carries water from the parent, distributing, channel to the module. The water then flows through a semi-circular rising pipe, which changes in shape from circular at its upper end to

the natural shape for free vortex flow at its lower end, whence the water passes into a semicircular open flume, called the 'eddy chamber'. In this, there is a series of 6 to 9 baffles, which are just clear of the on-flowing water. The principle on which it works is that when the head acting is the minimum required to cause 'free vortex flow', the water flows through the module without obstruction, but when the head exceeds this minimum, centrifugal force causes water to bank up on the outside of the semicircular 'eddy chamber' and impinge against the curved baffles, which cause the water to be thrown up with a rotary movement, thus dissipating its energy, after which it falls on top of the on-flowing water, further reducing energy.

The theoretical basis of the Gibb module is

(i) 'free vortex flow', in which the velocity at all points varies inversely as the radius, and

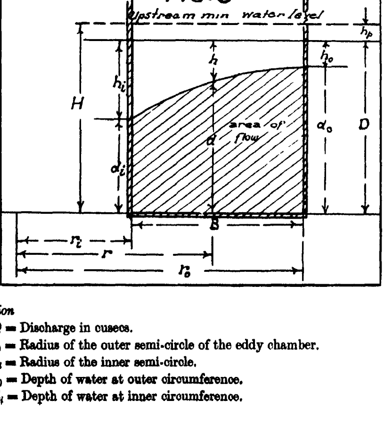
(ii) Bernoulli's theorem—the total energy head of all filaments remains constant.

$$V^2/2g+d+z = \text{constant},$$

where d = height of filament above bed,

and z = height of bed above datum.

FIG: 6



Notation

Q = Discharge in cusecs.

r_0 = Radius of the outer semi-circle of the eddy chamber.

r_i = Radius of the inner semi-circle.

d_0 = Depth of water at outer circumference.

d_i = Depth of water at inner circumference.

h = Head causing flow, varying from h_0 to h_i

$D+h_p$ = Total difference of level measured from the minimum water levels in the parent channel or distributary, to the floor of the eddy chamber, h_p being head lost in inlet pipe.

$m = \frac{r_0}{r_1}$ = Ratio of outer to inner radius.

B = Width of eddy chamber $= r_0 - r_i$

The general discharge formula was deduced at Poona and is as shown below —

$$Q = \int_{r_i}^{r_0} vd\,dr = \int_{r_i}^{r_0} \sqrt{2gh}\;d\,dr$$

Now $\quad vr = v_0 r_0 \quad$ or $\quad r\sqrt{2gh} = r_0\sqrt{2gh_0}.$

$$\therefore \quad h = h_0 \frac{r_0^2}{r^2} \quad \text{and} \quad d = D - h = D - h_0 \frac{r_0^2}{r^2}.$$

$$\therefore \quad Q = C\int_{r_i}^{r_0} \sqrt{2gh_0 \frac{r_0^2}{r^2}}\left(D - h_0\frac{r_0^2}{r^2}\right) dr$$

$$= Cr_0\sqrt{2gh_0}\int_{r_i}^{r_0}\left(\frac{D}{r} - h_0\frac{r_0^2}{r^3}\right) dr$$

$$= Cr_0\sqrt{2gh_0}\left\{D\log_e\frac{r_0}{r_i} - h_0 r_0^2\left[\frac{1}{2r_1^2} - \frac{1}{2r_0^2}\right]\right\}$$

Calling $\frac{r_0}{r_i} = m$

$$Q = Cr_0\sqrt{2g}\left[D\sqrt{h_0}\log_e m - \frac{h_0^{3/2}}{2}(m^2-1)\right]$$

and calling $h_0 = KD$

$$Q = Cr_0\sqrt{2g}\,D^{3/2}\left[\sqrt{K}\,[\log_e m - \frac{K^{1/2}}{2}(m^2-1)\right] \quad \quad (2)$$

The value of C—the coefficient of discharge—was found to be 0·935 from experiments.

Gibb standardised his modules for $m = 2{\cdot}0$ and $h_0 = D/7$.

The reason why geometrically similar results have been obtained with models of Gibb modules is because the dominant factor is gravity, which controls free vortex flow, and viscosity has only a negligible effect.

8. II. Models which are geometrically similar in shape, but do not give geometrically similar results.

An extreme example of this type of model is under test at Poona. This is a high-coefficient weir for Lake Arthur Hill at Bhandardara—Bombay Presidency.

The Waste Weir is 650 ft. long with a sill consisting of very uneven rock. Full supply level is 10 ft. higher at R.L. 2447·63. The object of the experiment was to design a waste weir which would store the maximum possible depth of water, and yet pass the estimated maximum flood without exceeding full supply level.

The maximum possible run-off from the catchment, estimated by the 'Inglis fan-catchment formula', $Q = \frac{7{,}000A}{\sqrt{A+4}}$ was 44,400 cubic feet per second (where A = area of catchment in square miles), but owing to the great 'flood absorptive capacity' of the Lake, the maximum discharge so far recorded over the existing waste weir has been 10,270 cusecs, and the maximum discharge which the weir would ever have to pass, based on a 4 hour peak period, worked out at 14,400 cusecs—according to Garrett's flood absorption formula.

Several difficulties had to be overcome in this model investigation. In the first place the problem was 3 dimensional, because in order to have as high a weir as possible its length was increased by making its alignment serpentine; so it was necessary to construct a model of the whole length of the weir; and it was decided to construct the full length model to a small scale (1/30) and even then it was 25 ft. long. This model had very small depths, and correct

Figure 7.

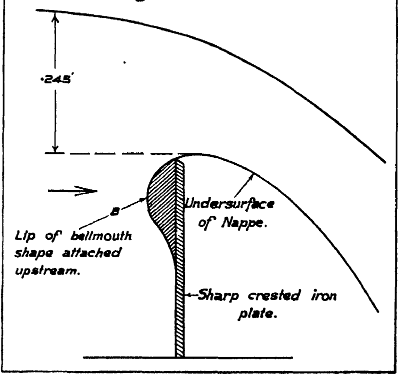


Fig. 8 – Showing coefficients of discharge with various scales of model.

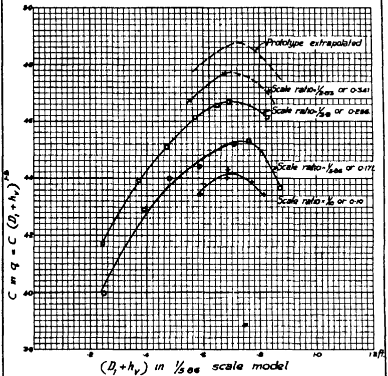
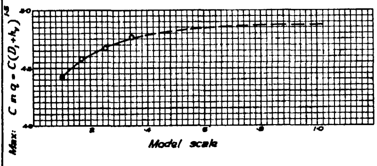


Fig. 9 – Showing maximum coefficient of discharge for various scales of model



relative roughness could not be estimated; so, to insure accurate downstream water levels,—which, as shown later, have an important bearing on results—a part model to a scale of 1/10 was constructed, which it was assumed would give similar results to the prototype—the Reynold's number exceeding 90,000—. A replica of this 1/10th scale part model was then constructed to a scale of 1/30, the roughness of which was altered until it gave similar depths to the 1/10 scale model, and the 1/30 full length model was then built with this same roughness.

Part models were also constructed to scales of 1/5·86, and 1/3·9. The high coefficient weir profile of the 1/5·86 scale model was constructed of a shape agreeing with the under side of the nappe of water flowing over a sharp-crested weir when a relatively small discharge was flowing, and a bell mouth lip was added upstream—as shown in Figure 7.

With a depth of ·243 the coefficient 'C' in the geometrically similar formula $q = CD^{1 \cdot 5}$ was 3·99. When q was increased, 'C' also increased, until a maximum coefficient of 4·53 was obtained with $D = \cdot 76$ ft. This

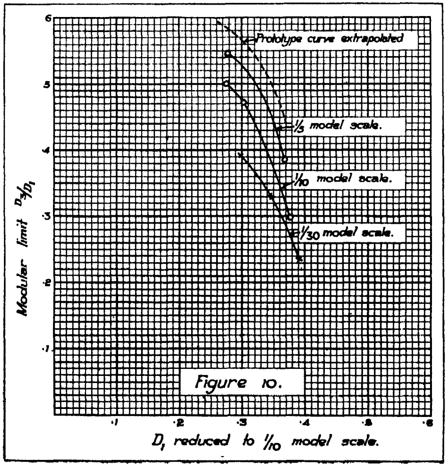


Figure 10.

increase was due to the effect of curvature of flow reducing the pressure and hence increasing the velocity, but when the discharge was increased further, the coefficient decreased rapidly, see Figure 8.

When the 1/10 scale, geometrically similar, model was tested in the same way it was found that the maximum coefficient was 4·42 while a model to a scale of 1/3·9 gave 'C' = 4·67 These maximum coefficients for various scales are plotted on Figure 9 with the curve extrapolated for the prototype With further improvement in the shape of the lip and crest, a still higher maximum coefficient of 4·65 was obtained in the 1/5·86 model against 4·53, and it is estimated that in the prototype 'C' would be 4·94 Flow in this case was neither parallel nor free vortex, and curvature introduced rapid changes in pressure and velocity gradients.

Up to this point, only free flow conditions have been considered, but another complicating factor arose due to the 'modular limit' varying with scale. Figure 10 shows the relation between $\frac{\text{(Depth upstream)}}{\text{(Vertical scale)}}$ and 'drowning ratios' at 'modular limit' for the various models (D_3/D_1 = drowning ratio 'Modular limit' is the maximum value of D_3/D_1 which just does not cause afflux for any particular discharge)

The coefficient of discharge also varied widely according to the percentage 'drowning ratio' in each model and was different for the same 'drowning ratio' in models of different scale

Actually, all these difficulties were resolved by adopting an alignment which, though serpentine, gave free flow over the whole length of the weir, and this was found to cause only a small reduction in storage.

This case is quoted to show how very wrong it is to assume that because a model is geometrically similar in shape, that therefore it will give geometrically similar results.

9. III. Regime models in which conditions of flow are maintained constant, with complete freedom as regards silting and scour

Channels may be divided into 2 main classes:—

(a) channels flowing within rigid boundaries, and

(b) channels flowing in incoherent alluvium.

In the former, flow is under flume conditions and a heavy super-charge of silt can be carried provided the slope is sufficiently steep In this paragraph, only channels in incoherent alluvium will be considered

Mr. Lindley, in his Paper on 'Regime channels' (published in *Proc Punjab Eng. Congress*, Vol. VII, 1919), put forward the original theory that 'the dimensions, width, depth and gradient of a channel to carry a given supply, loaded with a given silt charge, were all fixed by nature' and some ten years later Mr. Gerald Lacey in his Paper on 'Stable channels in alluvium' (*Proc. Inst. C.E.*, Vol. 229, 1929-30), produced a series of formulæ which fixed gradient

and shape of regime channels. These formulæ have gradually been winning acceptance all over the world.

The Lacey formulæ are the only formulæ which explain the known facts satisfactorily, so are here used to clarify flow problems in so far as they affect model work.

Lacey's formula

$$P \propto \sqrt{Q} = 2{\cdot}67\sqrt{Q}$$

(where P = wetted perimeter and Q = discharge in cusecs) is now generally accepted. From this

$$P^2 = 7{\cdot}12\ PRV$$

$$P/R = 7{\cdot}12\ V \qquad \ldots \quad \ldots \quad \ldots \quad (3)$$

(where R = hydraulic mean depth in ft and V = velocity in ft /sec)

On the Lacey assumption that regime channels approximate to an ellipse, the limit occurs when the channel becomes semi-circular; so, in the limit

$$P/R = 2\pi = 6{\cdot}2832$$

or $$V_{\text{lim}} = 0{\cdot}882\ f/s \qquad \ldots \quad . \quad \ldots \quad (4)$$

Similarly $$Q = PRV = 2{\cdot}67\ Q^{1/2}RV$$

or $$Q^{1/2} = 2{\cdot}67\ RV$$

$$Q = 7{\cdot}12\ (RV)^2$$

and according to Lacey's 'initial regime' formula $V = 1{\cdot}17\sqrt{fR}$ where f is the silt factor [$f = {\cdot}73\ V^2/R \propto (V^2/gR)$ (the Froude No.)] so

$$Q_{\text{lim}} = 1{\cdot}82\,f^2 \qquad \ldots \quad . \quad \ldots \quad (5)$$

These formulæ fix the theoretical low limit for regime V and Q according to the Lacey theory; but Figure 11, correlating Q and B_s (width at surface) and D_s (depth at midstream), show that according to this theory, the surface width increases rapidly for a small increase of discharge above the lower limit, while the depth decreases rapidly for a similar small increase above the lower limit, and although the minimum theoretical depth lies on a line $Q = 2{\cdot}1/f^2$, it is not till $Q = 3{\cdot}20/f^2$ that the depth in midstream becomes again equal to the Minimum theoretical depth for a semi-circular channel; and it is wise to avoid this range in model experiments.

It will also be noted that as the discharge required to establish regime increases inversely as the square of the silt factor, the coarser the silt, the smaller the discharge required. This result is analogous to the results of Nikuradze working with roughened pipes.

In practice the necessity for large models is demonstrated in connection with silt charge. In regime channels, for every discharge and type of silt there is a natural silt charge, and if the silt charge is in excess of this, the channel tends to throw down the excess, while if the water carries less silt than the regime charge it tends to pick up silt.

FIGURE 11

D_e IS THE DEPTH AT MIDSTREAM = MINOR SEMI-AXIS OF ELLIPSE
B_e " " WIDTH AT SURFACE AND $B_e/2$ = MAJOR SEMI-AXIS OF ELLIPSE
AT THE LIMIT — SEMI-CIRCLE — THE MAJOR SEMI AXIS
= THE MINOR SEMI-AXIS

THE LINE XX INDICATES SEMI-CIRCULAR DIMENSIONS FOR SILTS OF VARIOUS TYPES DEFINED BY LACEY SILT FACTOR \<FROUDE NUMBER

READINGS ABOVE THIS LINE REFER TO $B_e/2$
" BELOW " " " " D_e

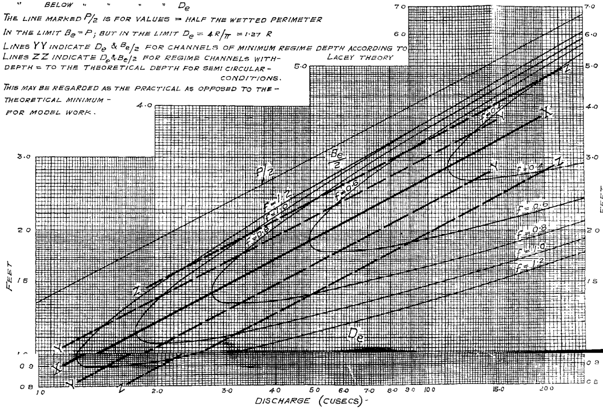
THE LINE MARKED $P/2$ IS FOR VALUES = HALF THE WETTED PERIMETER

IN THE LIMIT $B_e = P$; BUT IN THE LIMIT $D_e = 4R/\pi = 1{\cdot}27\ R$

LINES YY INDICATE D_e & $B_e/2$ FOR CHANNELS OF MINIMUM REGIME DEPTH ACCORDING TO LACEY THEORY

LINES ZZ INDICATE D_e & $B_e/2$ FOR REGIME CHANNELS WITH-DEPTH = TO THE THEORETICAL DEPTH FOR SEMI CIRCULAR-CONDITIONS.

THIS MAY BE REGARDED AS THE PRACTICAL AS OPPOSED TO THE-THEORETICAL MINIMUM-FOR MODEL WORK.



BY MUNNASINGH A.O.M

At Poona we have gone a considerable way towards determining the natural silt charge, and have found that the model silt charge is markedly different to that in the prototype. It has also been found that the smaller the model the more sensitive it is to a supercharge of silt

To sum up.—

(i) To obtain regime conditions the discharge of a model should exceed $3{\cdot}2/f^2$, so the limiting discharge necessary to create regime conditions varies inversely as the square of the silt factor (α Froude number) and much larger discharges and higher Reynold's numbers are required if the silt used in the model is fine

(ii) There is a natural regime silt charge, which varies with the discharge and silt grade, and there is a minimum velocity for each silt, below which the regime silt charge cannot be carried

(iii) For the same grade of silt, the lower the discharge, the more sensitive the model to a super-charge of silt

(iv) Regime models are not required for designing regime channels, because the Lacey formulæ give far more accurate results than can be obtained by applying model results, but they are particularly helpful in determining silt movements and the proportion of silt drawn by various offtakes and for indicating divergence from regime due to specific factors, for which purpose geometrically similar models and models based on scales selected arbitrarily give incorrect results The regime conception must, in fact, form the starting point of all accurate model work dealing with the movement of silt

10. IV. Combined Erodible and Rigid Models

(i) River-rigid-river succession

Owing to the fact that the approximate discharge formula of a barrage (or a weir) for varying discharges and that of a natural channel have different exponents of 'D' (the depth), either the length of the weir must be reduced as compared with the width of the River, or the sill of the weir must be relatively higher in the model than is the case in the prototype This would mean that the throat conditions would be different from those in the prototype and hence if a standing wave just formed in the prototype it would not form in the model, and downstream conditions would then be radically different. There would also be afflux upstream with low supplies. In other words, such a model would not reproduce prototype conditions. If, on the other hand, the vertical scale of the masonry work were made the same as the River vertical scale, retaining the same length of weir relative to the River width as in the prototype, conditions would be even more unnatural; because during floods there would be 'draw-down' at the masonry work with an unnaturally low water level and high velocity upstream of the masonry work. In fact, conditions in that case

would be completely wrong during floods, not merely upstream but also over the masonry work and downstream.

The author stresses this point, because it means that whenever a channel changes from natural (river) conditions to flume (rigid) conditions or vice versa, it is impossible, while maintaining the same scale in plan, to reproduce prototype conditions.

(ii) *River-rigid succession.*

If, however, conditions downstream of the model do not matter, and the correct relative levels in the prototype are known, it is possible, with the sill at the correct level relative to upstream bed level, to regulate downstream water levels so as to maintain correct upstream W L s. In the case of a Barrage, a better solution is to reduce the width of waterway of each span by thickening the piers near the gates in such a way that the vertical scale is the same for the Barrage as the river. In this way, conditions can be maintained approximately correct for all discharges.

(iii) *Rigid-river succession.*

Weir conditions and downstream conditions can generally be made to fit approximately by adjustment, but where one of the factors is expansion—as in the case of a Standing Wave Flume Meter Fall—vertical exaggeration, which has a marked effect on the permissible side divergence, prevents the model being similar in plan and the downstream divergence must be much sharper, which fits in with desirable shortening of the length of the weir.

In practice, expansion depends more on boundary conditions than energy and hence it is desirable to study results both in geometrically similar and vertically exaggerated models, which, considered together, make it possible to predict, with a high degree of accuracy, what will happen downstream in the prototype.

11. V. RIGID AND SEMI-RIGID MODELS, IN WHICH CONDITIONS ARE IMPOSED THE SIDES BEING HELD AGAINST SCOUR, E.G. TIDAL MODELS

In this type of model it is possible, owing to the flume conditions rendered possible by rigid boundaries, to exaggerate the vertical scale and slope beyond the natural vertical exaggeration of regime channels and hence to obtain results much more quickly and with much smaller models than with regime models.

There appears to be ample evidence to show that these models give valuable qualitative results provided they are correctly designed. It must, however, be remembered that conditions being to a large extent imposed, the model has little freedom to produce natural conditions and hence gives results which depend to a marked extent on the adequacy of the data and the skill of the experimenter.

Rigid models are used in America for determining the effect of 'cut-offs' on upstream water levels, and they give valuable information as to the immediate effect on water levels upstream, but that is all

12. VI. Models with mobile protection.

There are 3 main types of mobile protection,—

(a) Falling aprons,

(b) Spurs,

and (c) Pier and pavement protection.

Experiments have been carried out at Poona during the past two years with models of all these types. The dominant factor in this case is angle of repose, and as the angle of repose is little affected by scale, the models must be approximately geometrically similar in shape and have similar velocity gradients to those in the prototype It has been found at Poona that with Ganges River sand, Reynold's No should exceed 70,000 to obtain satisfactory results for application to the prototype, and discharges up to 21 cusecs have been used in the experiments.

13. VII Meandering river models and VIII. Combined rigid, mobile and meandering river models.

In India, the meanderings of rivers are generally affected by rigid structures chiefly railway bridges Two models at present under test at the Central Hydrodynamic Research Station near Poona will be described,—

(i) A model of the River Indus 170 ft long representing 7 miles above and 3 miles below the Sukkur Barrage,

(ii) A model of the River Ganges 600 ft. long representing the River from Sardah, 40 miles above the Hardinge Bridge (E B. Ry.) to the mouth of the Gorai River, 15 miles downstream.

14. (i) River Indus near the Sukkur Barrage

Figure 12 shows plans of the portion of the River Indus comprised in the model in 1930 and 1932. Between the rock gorge (in the vicinity of the towns of Sukkur and Rohri) and the barrage, both banks of the river have been pitched with stone, but silt has since deposited along the banks and so it is only in the gorge portion, where rock is exposed during floods, that flume conditions exist.

This model presents the following difficulties·—

(a) The river above the gorge swings between wide limits and this affects results below the gorge.

(b) Rock is exposed only during high floods and at that time a boat cannot be used for observing depths.

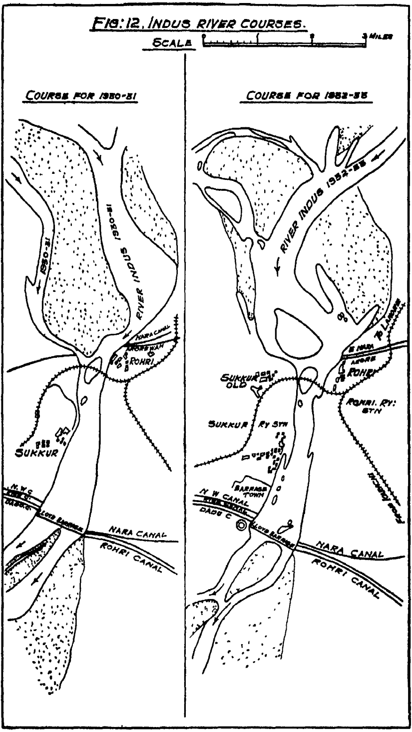


FIG: 12. INDUS RIVER COURSES.
SCALE
MILES
COURSE FOR 1930-31
COURSE FOR 1932-33
RIVER INDUS 1930-31
1930-31
NARA CANAL
ROHRI
SUKKUR
LLOYD BARRAGE
NARA CANAL
ROHRI CANAL
RIVER INDUS 1932-33
SUKKUR OLD
ROHRI
ROHRI. RY: STN
SUKKUR RY STN
BARRAGE TOWN
N W CANAL
DADU C
NARA CANAL
ROHRI CANAL

The data about rock levels is therefore meagre and this has had to be worked out by designing from experience, running the model to see results, and then modifying the rock contours until results tallied with those in the prototype. Though this may sound simple it presents extraordinary difficulties, not merely because changes take place in the river above the gorge during the flood season but also because the art of modelling to obtain desired results under fluctuating conditions can only be mastered by those with a natural aptitude combined with long experience, clear water being a 'sine qua non'

As a result of model experiments carried out 6 years ago to ascertain whether 'still pond' or 'open flow' regulation would be preferable for excluding silt from the Sukkur Barrage Canals (see *Bombay P.W.D*, *Tech. Papers*, Nos. 45 and 46), it was found that though 'still pond' regulation—which consists in keeping the undersluices between the Divide walls and the canals closed while the canals are flowing—gave slightly better results than 'open flow'—which consists in regulating by keeping some of the undersluices open—either method was successful for excluding coarse silt from the Left Bank Canals; but 'Still pond' regulation gave markedly better silt exclusion from the Right Bank Canals. This was fully confirmed when the canals were opened.

It was also predicted that a silt bank would form along the right bank and, to prevent this, it was proposed that a long vane should be constructed upstream of the canals on the right bank. This, alone, would have tended to pull the main flow of the river across to the right bank, so a similar vane was proposed for the left bank, and the two would have maintained channels free from heavy silt, along both banks.

This recommendation was not acted on, it being decided to watch results. In the floods of 1936, the river carried an exceptionally heavy charge of bed silt, and the predicted sand bank formed along the right bank from Bunder Station to the nose of the Divide wall of the Left Bank Canals and silting occurred in the North Western Canal. The original solution—a long vane—being no longer possible, experiments to find a new solution have been started This model gives highly accurate results.

15. (ii) Model of the River Ganges (600 ft. long) representing the River from Sardah, 40 miles above the Hardinge Bridge (E B Ry) to the mouth of the Gorai River, 15 miles below (Plate IV).

At the end of 1934, the author was called in by the Hardinge Bridge Committee to carry out model experiments and report on measures required to safeguard the Hardinge Bridge across the River Ganges, on which nearly a million pounds had been spent on repairs, during 2 years.

Five different sets of experiments were carried out:

(i) Pier experiments to determine the laws governing scour round piers, with (*a*) axial, and (*b*) cross flow; and the best way to protect piers against scour.

(ii) Falling apron experiments, to determine the way in which an apron, laid flat, launches under axial and curved flow conditions when the underlying material is (*a*) sand and (*b*) clay layers.

(iii) Experiments to determine the critical shape of pitched banks for stones of different shapes and sizes, and the final slope which the stones take up after launching under axial and curved flow conditions.

(iv) Large-scale model experiments to determine the exact conditions when the Guide Bank slipped—in order to determine how best to prevent a recurrence.

(v) Experiments with models of the River Ganges for the reach from Sardah, 40 miles above the Bridge, to below the Gorai River, 15 miles downstream.

Experiments (i) to (iv) all gave highly interesting and valuable results which had a bearing on the experiments carried out with the large model, but these cannot be dealt with here.

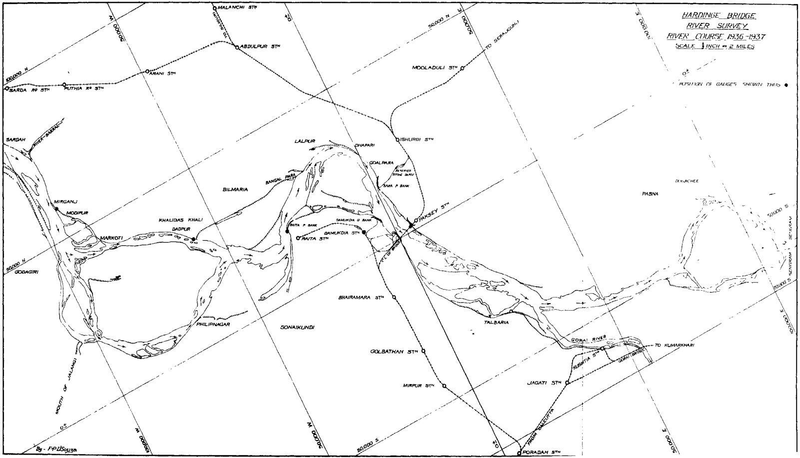
Plate IV shows a plan of the River from Sardah to the Gorai in the cold weather of 1936-37 after the breach had occurred.

Thirteen series of experiments were carried out with the big model; 10 before the Hardinge Bridge Committee issued their Report (see *Bombay P.W.D., Technical Paper* No. 55). These, taken in conjunction with experiments (ii) to (iv), showed that the conditions which led to the breach were due to severe action caused by the Sara Guide Bank, 19,000 ft. upstream of the bridge on the left bank, accentuated by the Damukdia Guide Bank, 11,000 ft. upstream of the bridge on the right bank. These Guide Banks turned 'high velocity, kinetic energy' into 'fiercely-eddying, surging flow', which cut away the toe of the Right Guide Bank, and so caused a serious slip, which later developed into a breach.

Alternative methods of reducing the attack were compared by model experiments, and the Committee decided, as a result, to remove the stone from the Sara Bank in order to reduce attack on the right guide bank. This has proved successful.

The above bald statements give little idea of the difficulties met with in carrying out the experiments.

In para. 11, dealing with combined river and rigid models, and para. 15, explaining the Sukkur Barrage experiments, some of these difficulties have been stated, but in this experiment further difficulties arose because the control points (*a*) Raita Guide Bank; (*b*) Sara Guide Bank, (*c*) Sara clay belts; (*d*) Damukdia Guide Bank and (*e*) the Right and (*f*) Left Guide Banks were all mobile and when attacked were liable to launch or even be partly washed away. This, it was impossible to reproduce in the model, because whereas the natural vertical exaggeration of the river portion of the model necessitates


HARDINGE BRIDGE
RIVER SURVEY
RIVER COURSE 1936-1937
SCALE ½ INCH = 2 MILES
POSITION OF GAUGES SHOWN THUS
MALANCHI STN
ABDULPUR STN
ARANI STN
SARDA Rd STN
PUTHIA Rd STN
MOOLADULI STN
TO SERAJGUNJ
ISHURDI STN
PAKSEY STN
SARDAH
RIVER BARRAL
MIRGANJ
MODIPUR
MARKOTI
GODAGIRI
KHALIDAS KHALI
DADPUR
BILMARIA
BANGAL PARA
LALPUR
DHAPARI
GOALPARA
RESERVED STONE DEPOT
SARA P BANK
RAITA P BANK
RAITA STN
DAMUKDIA G BANK
DAMUKDIA STN
C.L. OF BRIDGE
PHILIPNAGAR
SONAIKUNDI
BHAIRAMARA STN
GOLBATHAN STN
MIRPUR STN
TALBARIA
GORAI RIVER
GORAI BRIDGE
KUSHTIA STN
TO KUMARKHARI
JAGATI STN
FROM CALCUTTA
PORADAH STN
PABNA
DOGACHEE
SENGRAM
MOUTH OF JALANGI
100,000 N
50,000 N
50,000 W
100,000 W
50,000 E
100,000 E
50,000 S
By - F.P. D'Souza

steep slopes, a falling apron falls to a relatively flat slope, which for stone varies from 2 to 1 to 3 to 1.

It was therefore necessary to determine from large-scale model experiments under what conditions launching, slipping and washing away would take place in the prototype and to modify conditions from time to time when the model conditions indicated that a slip would occur

It was later found that in order to obtain similar 'throw-off' from these banks—i e. a similar velocity distribution and curvature of flow—the slope had to be different to that resulting from ordinary vertical exaggeration—i e there was a marked scale effect, so a series of experiments had to be done to find out how to correct for this scale effect in the model.

Finally, there was the difficulty that though the Eastern Bengal Railway have spent lakhs of rupees collecting data, it was totally inadequate, and the gaps had to be filled from experience, and except in the vicinity of the bridge there is no information about the strata below low water level and not much about the materials anywhere except at the surface

This model has now been experimented with almost continuously for nearly 3 years, and a book could be written on what has been learnt

One outstanding fact is that correct silt charge is an exceedingly important factor in this type of model, because it has been found that where there are 2 channels, one will open out with a particular silt charge and the other tend to silt, but with a different silt charge this may be reversed.

In this class of experiment, theory, except as a background, is of little help What brings success is a gift for diagnosing conditions,—enormously facilitated by clear water—and a capacity to prescribe the correct remedy.

15. SUMMARY AND CONCLUSIONS.

The author's original intention was to group over 100 successful model investigations carried out at Poona, touching on the salient features of each group Enumeration of the experiments had, however, to be omitted to cut down the length of the paper

Eight main types of models are described, with examples showing why some types present little difficulty and give results suitable for immediate application, whereas other types, especially those relating to alluvial rivers, present very great practical difficulties

Geometrically similar models in which parallel flow or free vortex flow are established give geometrically similar results provided they are not too small to make it possible to reproduce the boundary conditions of the prototype. In other cases full similarity is not attained.

It is only in some models of types I, II and V that parallel-sided flumes give reliable results, all other types should be treated as 3-dimensional problems

Channels may be divided into two classes:

(*a*) Channels flowing within rigid boundaries.

(*b*) Channels flowing in incoherent alluvium.

In the former, flow is under flumed conditions and a heavy super-charge of silt can be carried provided the slope is sufficiently steep. In the other type, flow is 'natural', adjustments to changing conditions being brought about by scouring and silting. Lindley, in 1919, put forward the original theory that 'the dimensions, width, depth and gradient of a channel to carry a given supply loaded with a given silt charge were all fixed by nature' and some ten years later Gerald Lacey produced a series of formulæ which fixed gradient and shape of regime channels.

According to Lacey, $P = 2{\cdot}67\sqrt{Q}$, from which it follows that $P/R = 7{\cdot}12\ V$, where P = wetted perimeter, Q = discharge, R = hydraulic mean depth and V = velocity. This is the Lacey 'final regime shape formula'. According to Lacey's 'initial regime formula' $V = 1{\cdot}17\sqrt{fR}$, where f is the silt factor, which $= 73\,\frac{V^2}{R}$, and hence is proportional to V^2/gR, the Froude number. So, on the assumption that a regime channel approximates to a semi-ellipse, with the semi-circle as the limiting shape, the limiting discharge in cubic ft. per second $= Q_{\text{lim}} = 1{\cdot}82/f^2$. Actually, however, for reasons explained in the paper, $Q = 3{\cdot}2/f^2$ is the minimum discharge with which it is safe to work.

From the Lacey formula and from Nikuradze's work on roughened pipes it follows that the finer the silt, the larger the discharge required in the model.

There is a natural regime silt charge, which varies with the discharge and silt grade, and there is a minimum velocity for each silt, below which the regime silt charge cannot be carried.

For the same grade of silt, the lower the discharge the more sensitive is the model to a super-charge of silt.

The regime conception must form the basis of all accurate model work dealing with movement of silt, and its division between offtakes.

Experiments with *combined erodible channels and rigid models* present difficulties; because the flow formula is different in the 2 parts, and hence a model which is identical in plan in model and prototype cannot give similar results. In many cases this can be overcome by 'fitting'. Part of the difficulty is due to the fact that though vertical exaggeration has been adopted as common practice in model work, lateral exaggeration, which is also natural, has, so far as the author can determine, been overlooked.

One of the best known types of models is the 'tidal model', which falls under the semi-rigid model type. In this, conditions are imposed, the sides, and in many cases a considerable part of the bed, being held against scour. Such models give valuable results provided they are correctly designed; but as conditions are imposed, either complete data must be available—which is practically never the case in river work—or else results depend to a marked extent on the field experience of the experimenter. Rigid models are used in America for determining the effect of 'cut-offs' on upstream water levels and

they give valuable information as to the immediate effect on water levels upstream, but that is all

Models with mobile protection, e g falling aprons, pier protection, etc., give geometrically similar results of great value

In almost all experiments except Type I, scale effect is important, and in practice, where conditions are normally complex this can best be determined by constructing 3 or more models of different sizes and analyzing the data, which, if found suitable, can be extrapolated to prototype scale.

Combined rigid, mobile and meandering river models present many difficulties, because the laws governing each of the 3 types, here combined, are different. To solve such problems, experiments to determine the scale effect of various factors have to be carried out in sets of separate models and the results of these combined and applied in the large, full length model, changes being made by hand when conditions arise which the other experiments indicate would lead to changes occurring

Though accurate results can be obtained in a model for one particular discharge, where discharges vary widely the degree of accuracy varies at different discharges and with low supplies difficulties arise in reproducing scour in the model. This can be partially overcome by selecting a suitable silt and having a varying discharge scale, but where the determination of scour with small discharges is important, separate large-scale part-models are required.

The main fact which follows from this paper is the importance of large 3-dimensional models, and at Poona the dischaiges now preferred range between 6 cusecs and 20 cusecs in each model, but may be as much as 30 cusecs in a single model, and up to 520 cusecs have been used in a model investigation of Type II

Although in general the larger the model the better the results, it must be remembered that doubling the size of a model, quadruples the area, the discharge, and the labour involved, and increases the time factor to approximately 1·6 times.

The general conclusion is that in competent hands, a very wide range of experiments with large models gives results of high qualitative accuracy and may also give quantitative accuracy, but, in the case of river models, the data available is generally meagre, and though the gaps in data can be filled to a large extent by an officer with wide field experience, so that a model can be made to reproduce what has previously occurred in the prototype under known conditions of discharge and silt charge, the problems which generally have to be tackled are of immediate urgency, the discharge data being inadequate and the silt charge data nil, and we are asked 'what will happen if nothing is done ?' or 'what should be done to prevent further damage ?'.

Satisfactory answers depend to a marked extent on an intimate knowledge of the engineering side of the problems under consideration combined with a flair for diagnosis.

RIVER PROBLEMS IN BENGAL.

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(*Read at Symposium, January 9, 1938.*)

FORMATION OF THE DELTA

No marine deposit within 1300′ depth.

1. In a joint note (published with the 'Report on the Hooghly river and its Head Waters', 1919) Messrs. Hayden and Pascoe of the Geological Survey of India state that "the absence of tertiary marine deposits, and the presence of tertiary fresh water deposits, throughout the outer Himalaya from Dehra Dun to Sikkim shew that, since the elevation of the Himalaya, marine conditions have not existed in that area, nor is there any evidence of the existence of such conditions at any point in the Gangetic plain between the Himalaya and the Peninsula." They admit that the evidence in support of this theory is rather meagre, being derived from a few borings at Ambala, Agra, Lucknow, Chandarnagore, Fort William and Port Canning, the deepest of which was only a little over 1,300 feet deep. But they argue that, in the absence of any evidence in favour of a contrary view, it would not be safe to reject the generally accepted conclusion, "that the conditions prevailing over the Indo-Gangetic plain from comparatively early tertiary times have not been dissimilar to those that exist at the present day, and that there has been a slow but gradual subsidence permitting of the accumulation of an enormous mass of alluvial deposits." In the 'History of the Rivers in the Gangetic delta' Mr C. Addams Williams, C.I.E., late Chief Engineer, Irrigation Department, has also given prominence to the view, 'that before the present upper strata of the delta were laid down, it appears that there was an older delta composed of materials totally different to those deposited by the Ganges. A stratum of yellow clay and sand appears to underlie that upper and newer strata of blue clay and sand. At Cowkhally on the lower Hooghly the yellow clay is about 60 feet from the surface as shown by borings taken in 1914. At Kushtia there are outcrops of the same stratum, and the general outcrop appears to be roughly round the extreme edges of the present delta'. Mr Addams Williams concludes, 'It appears that this delta was laid down by the rivers issuing from the north or north-east, and that presumably the Ganges had not then become a factor in the case. The old delta was depressed and the Ganges appears to have then entered on the scene and began forming the new delta on the top of the old, from the neighbourhood of Rajmahal'.

Enormous mass of alluvial deposits by the rivers.

The present delta built on another older delta.

2. In dealing with the river problems as we find them to-day we are really only concerned with the concluding portions of both the extracts quoted above which establish the point that the land we live in, up to a depth that we need think of, was built up gradually by the silt carried by the rivers mainly from the Himalayas and partly from the hills of Chhota-Nagpur and the Sonthal Parganas.

How the delta was formed.

3 To appreciate the river problems in Bengal it is necessary to envisage how the rivers, especially the Ganges, functioned in that early age and are still functioning in building the land and in extending it towards the sea The process of raising and extension of the delta towards the sea has been going on for thousands of years, and it will probably continue for an indefinite length of time as the stock of building material, *viz* detritus carried by the rainwater over thousands of square miles of catchment area, including a considerable portion of the mighty Himalayas, is almost unlimited

Stock of building material almost unlimited.

4 Millions of tons of this silt is thus being transported every year by the strong current of the Ganges flood and brought down to its mouth, where the current is checked by coming in contact with the sea and the silt in suspension drops into the bed. Land was thus formed at the head of the delta and as it began to extend, the Ganges, like the other delta builders, began to approach the sea in several diverging branches, enclosing and intersecting the delta already built, so as to raise it in the quickest possible time and to extend it towards the sea in ever-increasing width Each branch carried its due share of the silt-laden flood and as the bank on either side was low to start with, it was inundated during floods with the result that silt carried in suspension was dropped on the bank which was thus gradually raised, the raising being more rapid nearer the river

Thicker deposit close to the river.

5. Along with this process of raising the delta already built, so as to make it fit for human habitation, the other important function of extending the delta towards the sea was being carried on by the main volume of the floods carried down the several diverging branches dropping the silt near to their mouths.

A mere extension of the delta towards the sea-face would not be of much use, as what is required is that it should be sufficiently raised so as to be fit for human habitation and cultivation If the task of raising the delta was left entirely to the carriers of upland floods, the process would have been exceedingly slow as we can expect these floods only during the monsoon months, *i.e* only in 4 out of 12 months every year It is therefore in the economy of nature that the tides should come to our assistance in this respect. Tides flow up these rivers with strong velocity, twice daily throughout the year, and as there is a vast reservoir of unconsolidated silt at their mouths, deposited there by the

upland floods during the monsoon months, they pick up this silt almost to the saturation point on their way inland So long as the banks of these rivers within tidal limits are below the high-tide level and the rivers are free to spill, the silt laden tides perform exactly the same function as the upland flood, *viz* raising of the delta already built, with this difference that while the latter function only during the actual floods in the monsoon the beneficent activity of the tides continues throughout the year

Tides help in raising the delta

6 The second function of the tides is to fill up the interior of the delta lying between the upland flood carriers As mentioned above, the depth of silt deposit by upland floods, or by the tides carried up these rivers, is greatest close to the river banks, where the velocity, which determines the proportion of silt that can be carried, is first checked, and as the spilling proceeds away from the river banks the silt content of the spilled water and consequently the depth of silt deposit is less and less If nature had to depend entirely on this agency, the area lying midway between the contiguous upland flood carriers would have remained low—probably in the shape of creeks extending from the sea, till these rivers, after performing the function of raising the banks close to their channels would burst through the banks and follow the low valleys This would have been a slow process and to facilitate the work of delta building, here also nature requisitions the services of the tides which, picking up the silt on their way up these creeks or tidal rivers, gradually raise their beds and banks until they are raised up to high-tide level and rendered fit for cultivation There is no doubt that the source of this silt supply is the detritus carried to the sea by the upland floods for ages, but the tides by their constant movement keep it in an unconsolidated state and distribute it all along the delta-face between the two main estuaries, *viz.* those of the Hooghly and the Meghna

7 It will be clear from the above that nature has been employing both the agents, *viz* the upland flood carriers and the tides in her work of delta building She has been assisted in her task by two favourable factors, *viz* the high ranges of the Himalayan system of mountains, which have been furnishing the building material in abundance during the monsoon months, and the abnormally high tidal range, due to the funnel-shaped form of the Bay of Bengal, which has been helping in distributing these materials twice daily throughout the year But though the abnormal tidal range at the delta-face has been so helpful in raising the delta—in fact raising it higher than what would have been possible if the range was lower—this very fact, however, has stood in the way of rapid extension of the delta towards the sea; for, owing to the high tidal range, more and more of the alluvium brought down into the sea by the upland flood carriers is being dispersed along the delta-face to be picked up by the tides

Two agents employed by nature in building the delta - upland flood carriers and the tides.

travelling inland through innumerable tidal channels, and less and less of it has been deposited in a consolidated state to extend the delta.

High tidal range helpful to navigation.

8. The high tidal range has also been helpful to navigation and it is not surprising that the people of Bengal look upon the rivers, both tidal and non-tidal, with veneration, for they created the land, are draining and fertilizing it and are helping in carrying the produce Fertilization by tidal silt may not be apparent, but as the source of this silt is really what is carried by the upland floods, the manurial properties of which are so highly valued, it is only a question of time, i.e after the salt carried with the tidal silt has been washed away by rains, before its fertilizing properties are manifested as is so amply demonstrated in the case of the reclaimed land in the Sunderbans

Function of rivers in Bengal.

Rivers are an essential factor in Rural Development.

9. Bengal being mainly an agricultural country, the rivers are the principal source of the economic wellbeing of the people. Where they are still active and are performing their original functions, as in East Bengal, the people are healthy and prosperous, where they are deteriorating and their beneficial activities have been interrupted, either due to natural causes or through human interference, as in Central and Western Bengal, the area is progressively deteriorating both as regards the health of the people and the productivity of the soil. River problems in Bengal are thus virtually the problems for Rural Development in Bengal and have to be solved if she has to be saved, especially her western and central parts which even as late as a century ago used to be very healthy and prosperous, from reversion to swamps and jungles from which she was reclaimed by the rivers.

Rivers classified into three groups.

For a proper appreciation of the 'River problems in Bengal' and their solution it would be convenient to classify the rivers, having regard to their special characteristics, into three groups as indicated below

10. Group I —Primary delta builders originating from the snow-capped Himalayas, maintaining a more or less perennial flow and navigable especially in their lower reaches.

The principal rivers in this group are (*a*) the Ganges series including the tributaries and the spill channels, (*b*) the Brahmaputra series including the Teesta and (*c*) the Meghna. By far the most important delta builder is of course the Ganges which, traversing a length of 1,540 miles and draining an average annual rainfall of 42 inches over a catchment area of 397,500 sq. miles and with the recorded maximum flood discharge of about 2,000,000 cusecs (at Sara) has been mainly responsible in building, raising and fertilizing the delta. The Brahmaputra was originally a comparatively small river, but since her connection with the Tsan Po of Tibet through her tributory the Dihong (in Upper Assam), and subsequent additions of the floods of the

Teesta (since 1787), she has been a formidable rival of the Ganges and promises to play a more and more important part in the future She now traverses a length of 1,800 miles and drains an average annual rainfall of 88 inches (in the Assam valley) over a catchment area of about 361,000 sq miles

11. Group II —Primary delta builders originating from the low hills of Chhota-Nagpur and the Sonthal Parganas such as the Damodar, the Ajay, the More, the Cossye, etc. They are torrential rivers, the flow being mainly confined to the monsoon months from June to September Though they bring in enormous volumes of floods at times (the maximum flood discharge of the Damodar, the largest of the group, with a catchment area of 7,200 sq miles, amounts to as much as 650,000 cusecs), they dwindle down to a mere trickle sometimes even during the rainy season, and during the dry season there is practically no flow Though their contribution towards the building of the delta could not be much compared with that of the Ganges, it is believed that the eastern portion of the Burdwan district and the western portion of the Hooghly and Howrah districts owe their origin to the delta building activity of the Damodar, and the eastern portion of Midnapore district to that of the Cossye and the Rupnarain. Their value, however, lies in the fact that they constitute the only source available for supplying the water needed for artificial irrigation and for flood flushing I shall deal with flood flushing later but I propose to discuss the necessity of artificial irrigation and how this aspect of the problem can be solved at this stage, as irrigation is required in Western Bengal

Irrigation required in Western Bengal.

12. Though the total rainfall in Western Bengal is sufficient in normal years its distribution during the crop period is erratic, especially after the middle of September, when the rainfall is hardly sufficient to meet the requirements of the paddy crop Even in normal years artificial irrigation is thus a necessity in Western Bengal to ensure a normal harvest To provide an insurance against famine it is a vital necessity in years of abnormally low rainfall, which occur say once in 5 to 7 years. Again, since practically the whole of the rural population lives on agriculture and the allied industries and the *raiyats* are too poor to afford artificial manure, canal irrigation, by providing natural manure in the shape of highly fertilizing silt carried by the canal water, seems to be the only means available for increasing the yield from the land and improving the economic condition of the people.

Erratic distribution of rainfall in Western Bengal.

Irrigation the only means of improving the economic condition of the people.

I do not propose to lengthen this paper by dealing in detail with this important factor in rural development in Western Bengal, as this aspect of the problem and its solution is more or less similar to what is being experienced in the rest of India. I shall merely emphasize some of the points that have

come to my knowledge in the course of my official duties and then pass on to other aspects of river problems which are peculiar to Bengal.

13 Bengal has an important advantage over the rest of India in the fact that during the transplantation season, when a very large quantity of water is required by the crops, the rainfall is usually adequate. In fact in normal years artificial irrigation is usually required to meet the deficiencies of the north-eastern monsoon from the middle of September to the end of October Unfortunately this is the very time when the rivers in Western Bengal also bring in a rather scanty flow, though earlier in the season, *i e* during the south-western monsoon, they usually bring in enormous volumes of floods which run to waste. It is, therefore, apparent that to meet the irrigation needs of Western Bengal storage is a necessity, *i.e* the water should be stored in natural storage works constructed in the upper valleys of these torrential rivers in Western Bengal during floods and utilised in times of scarcity. Storage works are no doubt costly, but as stored water has to be supplied mainly in October, when the requirement of crops is minimum, they are likely to be profitable undertakings in Bengal The area that could be irrigated by a stream by its daily flow can be increased many times over if only a portion of its flood could be stored and utilised in times of scarcity to supplement the daily flow In Madras, where storage works are also needed for the transplantation of paddy owing to the failure of the south-western monsoon, 1 m. Cft. of stored water can irrigate only about 5 acres In Bengal, on the other hand, for the reasons mentioned before, it can irrigate over 30 acres Again, for growing sugarcane and *rabi* crops storage works seem to be an absolute necessity, as from November till April no rain is usually expected in Western Bengal

Necessity for storage to supplement the river flow.

14. But though storage schemes seem to be an absolute necessity for the development of irrigation and the economic uplift of the people in Western Bengal, owing to the flatness of the country it is difficult to obtain suitable sites for storage dams within the boundaries of the Province For good sites we have really to search in the upper valleys of these rivers lying within the hilly regions of Chhota-Nagpur and the Sonthal Parganas in the Province of Bihar Two good sites have been discovered so far in connection with the investigation of the Dwarkeswar and More projects, and it is estimated that by constructing suitable storage works, etc, about 200,000 acres can be irrigated by the former and 432,000 acres by the latter

Scarcity of sites in Bengal for storage schemes.

More and Dwarkeswar Reservoir Projects.

15. Group III:—Subsidiary delta builders or tidal rivers These are mainly the lower reaches of the rivers of groups I and II within tidal limits which, as has been explained above, continue their beneficent activities of raising, fertilizing and draining the lower portion of the delta twice daily throughout the year and help in transporting the produce of the whole country,

River Problems with reference to health and productivity of the soil.

16 In all the accounts that have been preserved from ancient sources Bengal is reported to have been healthy and prosperous Bernier wrote about the middle of the 17th century "The knowledge that I have acquired of Bengal in two visits inclines me to believe that it is richer than Egypt" Even as late as 1815 Hamilton wrote of Hooghly, Howrah and Burdwan, which area is now one of the worst as regards health and impoverishment of the soil, as follows "In productive agricultural value in proportion to its size, in the whole of Hindusthan Burdwan claims the first rank and Tanjore second" In her eastern parts where she is being nourished by her rivers, Bengal still continues to be prosperous and healthy Even in the rest of Bengal there is no dearth of water resources but the growing deterioration in the health and in the productivity of the soil has to be traced to their faulty distribution Through some streams more water flows than is necessary, frequently causing disastrous floods, while at other places the scanty flow through natural waterways has caused serious deterioration, in many cases rendering them even incapable of draining the countryside Indeed, many of these streams which were originally intended by nature —this is a phenomenon peculiar to deltaic areas—to spill over the land which they traverse and keep it in plenty by supplying the rich silt of the Ganges, the Damodar, etc , have now been converted into stagnant pools of water providing an excellent breeding ground for mosquitoes, and many a district of Bengal especially in the centre and in the West has been rendered extremely unhealthy with steadily decreasing population and with land gradually going out of cultivation

Bengal highly prosperous even about a century ago

Progressive deterioration due to faulty distribution of water resources.

17 This faulty distribution of the available water resources which has brought about the present deplorable condition is attributable partly to human interference with the natural process of building up the delta and partly to natural causes The most prominent instance of human interference which has mainly affected the rivers of groups II and III referred to above is to be found in the flood embankments, mainly in Western Bengal, but partly also in Central Bengal which, by cutting off the flood spill and depriving the land of natural manure, have killed the net-work of natural spill and drainage channels within the area and have brought about the present deplorable condition

Faulty distribution due to human interference and natural causes.

18 There is no dearth of natural hydraulic resources. In fact Bengal has been highly favoured by nature in this respect. The rainfall, though somewhat erratic in distribution in the western parts, is normally quite adequate to meet the requirement of at least the *Kariff* crop in other

parts, and Bengal can count on abundant monsoon floods to nourish her soil with fertilizing silt and to kill the mosquito larvæ if only these floods could be properly distributed. A more equitable distribution of the water resources is thus vitally needed for the rural development of Bengal. I shall now go into the question somewhat closely dealing with each group of rivers separately and examine a representative type of each group in detail

Solution lies in more equitable distribution of the abundant water resources available in Bengal.

Rivers of Group I.

Primary Delta Builders originating from the Himalayas.

19. The areas which have been adversely affected mainly by natural causes, *i e.* by major changes in the courses of the rivers of this group, are (1) in Central Bengal by the diversion of the Ganges through its present channel of the Padma sometime towards the beginning of the 16th century, (2) in North Bengal by the diversion of the Teesta sometime towards the end of the 18th century (1787), and (3) in portions of Mymensingh district by the diversion of the main Brahmaputra through the present Jamuna channel soon after. There is no doubt as regards changes (2) and (3) as they occurred comparatively recently and can definitely be proved by reference to Rennel's maps which were prepared earlier. Before the diversion, the Teesta used to discharge its waters through the Panarbhaba (a tributary of the Mahananda), the Atreyi and the Karatoa which used to fall directly into the Ganges. The large number of spill and drainage channels which intersect Northern Bengal were, in consequence, allowed to continue their beneficent activities as explained above and the area was healthy and prosperous After the diversion of the Teesta, completely cutting off the head-water supply laden with fertilizing silt from the Himalayas, these channels are gradually deteriorating, bringing in their train water-logging due to inadequate drainage and progressive deterioration of the country as regards health and productivity of the soil.

Major changes in the river courses have caused deterioration in Central and Northern Bengal and in Mymensingh district.

20. Even as regards the Ganges it seems to have been an admitted fact hitherto that the Bhagirathi originally constituted the main course of the Ganges till the end of the 15th century when the main channel was diverted along the present Padma channel. In recent years, however, this view has been challenged by the late Sir William Willcocks who, in a lecture delivered before the Calcutta University in 1930, has propounded the rather extraordinary theory that the Bhagirathi and other rivers in Central Bengal were originally really canals excavated by the old Hindu rulers of Bengal for the purposes of overflow irrigation,

Canal theory regarding the origin of the Bhagirathi untenable.

As the challenge has come from a delta Engineer of the reputation of Sir William, it seems necessary to examine this point in some detail

21 A glance at the map of Bengal will show that the extension of the delta towards the sea is greatest towards its western end, i e along the Hooghly estuary, and least at its eastern end, i e along the Meghna estuary, the present outfall of the Ganges. This is in spite of the fact that the Meghna estuary is also receiving the flood of the Brahmaputra which, since her connection with the Tsan Po of Tibet, is probably much larger in volume than that of the Ganges This ought to serve as conclusive evidence in support of the established theory that the main volume of the Ganges flood, which constitutes the main delta builder, has been passing down the Hooghly estuary for a much longer period than along the Meghna as at present, unless it can be proved that there were other delta builders discharging into the Hooghly and contiguous estuaries to the east, floods even larger in volume than that of the Ganges, Brahmaputra and Meghna combined Such a river does not exist and could not possibly have existed in the present geological epoch Taking the present geological disposition of watersheds and considering the present meteorological conditions, such a river or rivers could have drained only an average rainfall of about 50 inches from the catchment area of about 25,000 sq miles, which is roughly the combined catchment areas of the rivers of Western Bengal originating from the hills of Chhota-Nagpur and the Sonthal Parganas. As compared with this, the Ganges alone drains an average rainfall of 42 inches over a catchment area of 397,500 sq miles, and the Brahmaputra, even before her connection with the Tsan Po of Tibet, had a very large catchment area in the submontane region of Assam with an average rainfall of about 88 inches According to Sir William Willcocks the south western portion of Central Bengal was also built up by the Damodar. That this theory is not at all tenable will be apparent from the fact that the Damodar has a catchment area of only 7,200 sq miles with an average rainfall of about 50 inches Its maximum flood discharge is only 650,000 cusecs as compared with 2,000,000 cusecs of the Ganges Floods of this order again occur only at long intervals (1913 and 1935) and are short-lived, of not more than 2 or 3 days at a time The average flood discharge of the Damodar and all the Western streams combined will be a mere fraction of that of the Ganges

Evidence in support of the established theory that the Bhagirathi was the original course of the main Ganges.

22 Among other evidences in support of the established theory the following may be mentioned —

Religious and traditional evidence.

From the mythological period the Hindus have considered the Ganges as sacred and people by thousands have been going on pilgrimage to places on the banks of the Ganges such as Navadwip, Katwa, Tribeni (a few miles above

Hooghly town and also called Mukta Beni where the Ganga, Jamuna and Saraswati, which were united at Allahabad, were separated), Kalighat and Ganga Saugor, all situated on the Bhagirathi or the Hooghly below the present offtake from the Ganges No such sanctity attaches to the Padma below the Bhagirathi offtake nor is there any place of pilgrimage on her banks (*N.B* Major Hirst has dealt with this matter more fully in his report 'Nadia Rivers, 1915')

Historical evidence

Pliny (116 A D) and Ptolemy (140 A D.) mention Tribeni referred to above Arrian (161 A D) refers to Katadupa or Katwa (Notes by Mr Reaks published with the report on the Hooghly river and its head waters.) No such places of antiquity are found on the banks of the Padma

I am also informed by my brother Dr R C Majumdar of the Dacca University that there is indisputable historical evidence, for instance, in the Khalimpur Copper Plate of King Dharmapala (780-820 A D) to show that the Ganges, even above Rajmahal, was also called the Bhagirathi in the olden days The Padma has never been called by this name, but the western branch is still called the Bhagirathi, thus establishing the point that the latter was really the main course of the Ganges, and that the Padma (if it was really in existence then) was either unconnected with that river in the olden days, or it was a branch not large enough to claim the honour of bearing the same name with the main river

23 It is also a matter of history that Gaur on the Bhagirathi was the capital of Bengal up to the beginning of the 16th century, and I quote the following from Major Hirst's report on "Nadia Rivers" (1915) to shew that the Padma could not have existed in those days as a branch of the Ganges and, even if it did exist, it must have been a comparatively minor channel, as otherwise both the upper and lower reaches separated by the Padma could not have been named the Bhagirathi as we find it up to the present day —

"The upper Bhagirathi (Gaur arm) meets the Ganges and the Padma at the place where the Ganges loses its name The lower Bhagirathi (Upper Hooghly) emanates from the present Ganges on the south bank practically opposite the mouth of the upper Bhagirathi. The alignment of the upper and lower Bhagirathi streams is essentially one which a river would follow and the only portion of the alignment that is missing is occupied by the main bed of the Ganges. From this fact it is clear that if the upper Bhagirathi was the main Ganges originally, and the history of Gaur proves that point, then the Padma as a main river is a more recent channel than the Bhagirathi upper and lower."

24. Major Hirst further remarks that "There was a severe earthquake in 1505 A D and shortly after it, the Ganges left its old course past Gaur and retreated southwards The cause of this great change is not known, but it may have been due to earth movements between the old alluvium of Malda and Chhotanagpur outliers" In fact Major Hirst attributes the major changes of the river courses in Bengal to tectonic activity which theory has not, however, been accepted by geological experts (Messrs Hayden and Pascoe of the Geological Survey of India, *vide* Report on the Hooghly river and its Head waters, 1919)

Major Hirst's explanation for major changes in the river courses.

25. But it does not seem to be necessary to rely on tectonic activity to find an explanation for the changes in the courses of rivers in deltaic Bengal which seem to be not only inherent in their very nature but necessary for the purpose of building and raising the delta

In the process of building up the delta, the river has a tendency to oscillate within wide limits, first, flowing on one side and after the riparian tracts have been raised to a certain extent, it bursts through its banks and opens up new channels through the comparatively lower areas of the contiguous tract and so on After these latter areas have been raised sufficiently the process is reversed to raise still higher the tract which has been raised already This is perfectly consistent with the natural conditions governing the flow of a river which, following the immutable laws of nature, always tends to take the line of least resistance The lower land not only gives it a better hydraulic slope but by providing better facilities for spill, and consequently abstracting large portion of its silt burden, helps to maintain the river in a more efficient condition than if it has to pass through higher land

Simpler explanation offered which seems to be more probable.

26 Before the diversion of the Ganges, the Mahananda and North Bengal rivers probably had an independent outfall more or less along the present Padma channel The shifting of the Bhagirathi or the Ganges southwards of Gaur, mentioned by Major Hirst, made the condition favourable for a cut-off between the left bank of the Bhagirathi or the Bhairab which probably constituted the easternmost branch and the right bank of the Mahananda Owing to the existence of lower land to the east, which had not received so much attention hitherto as the western area as regards delta building activity, this Mahananda outfall after the above cut-off, rapidly developed and constituted the main course of the Ganges and the lower Bhagirathi began to deteriorate

Central Bengal.

27. There is no doubt that Central Bengal has been built up by the silt carried by the Ganges which, in the olden days, used to distribute her waters mainly through the Bhairab, which probably constituted the easternmost branch, and the Bhagirathi in the lower reaches, trifurcated into three

main branches at Tribeni a few miles above Hooghly, *viz.* the Jamuna, the Bhagirathi (or Hooghly) and the Saraswati. Since the diversion of the Ganges flood, however, through the Padma channel, these rivers began to deteriorate.

Central Bengal—built up and fertilized by the Ganges before her diversion.

The Bhagirathi, which once constituted the main channel of the Ganges, now remains practically cut-off from this river, except during floods, and moreover the share of the Ganges flood it now receives is almost insignificant as compared with what used to pass before the diversion. In consequence, its western and eastern branches, *viz* the Saraswati and the Jamuna, are now dead and the Bhagirathi also would probably have shared the same fate but for the rivers in Western Bengal, which have their outfalls into this river, and the tidal flushing in the lower reaches which, thanks to the conservancy measures of the Calcutta Port Trust, is being allowed as freely as is possible. In the upper reaches, however, the river is fast deteriorating and even in the lower reaches its condition is not free from anxiety as further deterioration will threaten the very existence of Calcutta as a Port. The Bhairab also is now dead having been cut through first by the Jalangi and then by the Mathabhanga These latter rivers opened up comparatively recently after the diversion of the Ganges but they are also fast deteriorating (partly due to artificial interference) and, though not completely dead yet, can no longer draw sufficient water from the Ganges to be able to spill over the land nor to keep their distributaries alive The large number of distributary channels such as the Nabaganga, the Chitra, Kobadak, Betna, Kodla, etc., which used to distribute this spill equitably over the entire area, have also died or are dying, resulting not only in the progressive impoverishment of the soil but acute difficulty in drainage and water-logging Practically the whole area traversed by these channels is highly malarious and unless the old conditions of flushing by the Ganges flood can be restored, this area will gradually revert to swamps and jungles from which it was reclaimed by the rivers.

After the diversion, the spill channels deteriorated.

28. The principal spill channels which are not yet completely dead and on which we have to depend for the purpose of drawing from the Ganges and carrying a portion of her flood for flushing this area are the Bhagirathi, the Jalangi and the Mathabhanga. In view of the apparent tendency of nature to enrich the Padma at the expense of these rivers, the question of primary importance to be considered in connection with their improvement is whether an appreciable portion of the Ganges flood can at all be induced to pass through them in preference to the Padma of which the hydraulic conditions are of course much more efficient. The late Sir William Willcocks advocated the construction of a barrage across the Ganges with a view to induce a portion of the Ganges flood to pass through these channels, But the cost of the barrage together

Technical feasibility regarding the restoration of the Ganges spill considered.

with that of the river protective works that would be necessary to prevent outflanking and their maintenance would be so heavy that those who have to finance the scheme may not be disposed to seriously discuss it in the present economic condition of Bengal We have, therefore, to consider the question of improvement of these rivers without the barrage

Ganges Barrage.

29. It may first be considered whether the Ganges has permanently or only temporarily forsaken this tract In view of the characteristics of deltaic rivers as explained above, especially in para 25, it seems reasonable to expect that after the Ganges has raised the tract through which she is now flowing, she will again turn her attention to Central Bengal and the present decadent rivers of these parts may improve It may be mentioned here that an authoritative Committee recently examined the question of the head waters of the Hooghly and, after examining all the evidences on the subject, stressed the importance of the Ganges freshets carried by the Nadia rivers (Bhagirathi, the Jalangi and the Mathabhanga), and came to the conclusion that these rivers pass through successive phases of deterioration and improvement and that there is no definite proof that they have permanently deteriorated to any great extent (*Report on the Hooghly River and its Head Waters*)

30. In this connection it may be mentioned that diversion of the Brahmaputra through the present Jamuna channel, which meets the Ganges just above Goalundo, might have given some of these Nadia rivers (at least the Mathabhanga which is nearest to the junction) a chance of revival The Brahmaputra flood usually reaches the junction earlier and acts more or less as a barrage trying to hold up the Ganges flood to seek some other outlet higher up But, unfortunately for the Nadia rivers, such an outlet was found in the Gorai which, in Rennel's time, was only a minor channel but which has since considerably developed. As there is an extensive area of low land yet to raise, the Gorai will probably continue to develop In fact, even apart from raising and fertilizing extensive areas of low land along her left bank in the District of Faridpur, thanks to the Halifax Cut made by the District Board of Jessore in 1901-02 connecting the Madhumati (lower reach of the Gorai) and the Nabaganga, the Madhumati is now discharging the delta building functions, left unfinished by the Bhairab and the minor spill channels Nabaganga, Chitra, etc., in the eastern portions of Jessore and Khulna districts. It is, however, possible that after these lower areas have been raised the barrage effect caused by the Brahmaputra flood may even reach the neighbourhood of the Mathabhanga offtake and a larger portion of the Ganges flood might be induced to flow down that channel.

Barrage effect of the Brahmaputra flood.

Development of the Gorai.

Afflux created by the Hardinge bridge not material so far.

31. The popular view is that the Hardinge Bridge, which was completed in 1915, might also help in improving the Mathabhanga. But the offtake of the Mathabhanga being located about 25 miles higher up the Ganges, it does not appear that the bridge has caused a sufficient afflux yet to effect any material improvement of the Mathabhanga

About half the width of the Ganges underneath the bridge has however silted up well above the low water level along the left bank As widening of the channel along the right or southern bank is being prevented by extensive bank protective works and as deepening by scour is being restricted by extensive stone dumping round the piers, it seems possible that this bridge may in future act more and more as a barrage, with larger and larger afflux, holding up the Ganges flood to seek an outlet higher up If, however, the afflux increases materially, it seems more likely that the river will find this outlet in the Lalpur bight, a few miles above Sara on the left bank, and there will be an avulsion through the extensive low areas near about Chalan Bil, outflanking the Hardinge bridge on the north But till this catastrophe occurs, the effect of the increase in the afflux, if any, will probably be to improve the Mathabhanga

But it may increase to the advantage of the Mathabhanga and may even induce far-reaching changes in the regime of the Ganges.

32 We may have to wait for decades or perhaps centuries before nature turns her attention to Central Bengal and the point for consideration is whether it is not possible to effect any lasting improvement of these rivers by artificial means. Railway authorities should also be interested in this matter, for diversion of an appreciable portion of the Ganges flood through the Nadia rivers ought to relieve the pressure on the Hardinge bridge thus reducing the cost of its maintenance and averting a possible danger of avulsion on the left bank as discussed above The recent changes in the Ganges which might be attributable to the causes referred to above seem to be hopeful. The huge *char* which hitherto masked the offtake of the Mathabhanga has practically disappeared and its position in relation to the Ganges is definitely improving. The offtakes of the other two principal spill channels in Central Bengal, *viz.* the Jalangi and the Bhagirathi are also showing signs of improvement though not to the same extent as the Mathabhanga

Mathabhanga offtake appears to be improving.

33. But mere improvement of the offtakes is not enough. it merely shows the tendency of nature To be able to utilise fully these tendencies to our advantage, it is necessary to improve the carrying capacities of these channels and provide suitable outlets of distributory channels of adequate capacity, and other facilities for spill over the country side. For, unless the increased discharge that could be drawn in view of the favourable position of the offtakes, could be carried by these channels and disposed of, no material improvement over the present condition can be expected The function allotted by nature

to these spill channels in deltaic Bengal is that they should spill over the land during floods and deposit the highly fertilizing silt carried by the flood water Being relieved of the silt burden, the comparatively clear water should then flow down these channels and maintain them in an efficient condition If it is not allowed to spill a good portion of its silt content, the flood water entering these channels, owing to the reduced velocity due to flatter gradient available in the lower portion of Bengal will not be able to transport the large quantity of silt and will deposit it in their beds, thus again deteriorating the channels Improvement by dredging or by hand cut, where feasible, will no doubt be necessary initially to give these works of improvement a good start But it is impossible to maintain a river by dredging alone, for, apart from the question of cost, the dredged soil has necessarily to be deposited on the banks close to the river channels, which will go on rising as the dredging continues and soon reach a height beyond the lift of the dredger An essential condition of success, therefore, is that, after their initial improvement, forces, which were in operation before, when these channels were in a live condition, should be restored so that they may again be self-maintaining or, in other words, they should be allowed to spill extensively over their banks without hindrance as far as possible To what extent this may be feasible, it is not possible to say without a contour survey with lines of levels taken at fairly close intervals, and detailed investigation made as regards the vested interests that are likely to be adversely affected, and the remedial measures to be adopted to safeguard those interests The problem is undoubtedly a very complicated one and what I wish to emphasise is that no piecemeal solution is really possible, and the problem has to be thought out and dealt with comprehensively.

Dredging alone cannot maintain a channel permanently.

Land flushing essential for the preservation of spill channels.

34 About one point, however, there seems to be no doubt, *viz* the necessity for a substitute crop in the lower areas which will not be affected adversely by uncontrolled flushing when the Ganges is in flood in August and September In the case also of these lower areas, mostly '*bils*' and '*baors*', the problem to be solved is one of premature reclamation But since the vested interests have already been created and now constitute the source of livelihood of a large number of people, we have to face the problem as it stands and find a solution The only practicable solution appears to be that *raiyats* should be encouraged to grow in these *bills* and other lower areas a crop which can be harvested before the Ganges rises sufficiently high early in August, or a crop like the long-stem paddy of East Bengal which grows with the rise in water level and will not be damaged by uncontrolled flushing In any case, unless a practicable solution can be found for this problem, the prospect of flood flushing schemes for Central Bengal, which appears

Introduction of a substitute crop for the lower areas of Central Bengal seems to be an essential preliminary to flood flushing scheme.

to be urgently necessary to arrest the growing deterioration in health and productivity of the soil, as also to revive the dying spill channels, seems to be rather gloomy. It does not appear to be feasible to have controlled flushing without a barrage across the Ganges, the cost of which will of course be prohibitive. But even if the flushing could be controlled, the lower land, the *bils* and other low areas are likely to be inundated, in the process of flushing to a depth which will probably make it impossible to continue the present method of cultivation We had practical experience of this difficulty during the recent high floods when, owing to the abnormally high flood level of the Ganges and of its spill channels, the crops over a large area of Central Bengal were damaged. Necessity for growing in these low areas a suitable substitute crop, as an essential preliminary step before launching a flood flushing scheme, cannot therefore be exaggerated.

Group II —PRIMARY DELTA BUILDERS ORIGINATING FROM THE HILLS OF CHHOTA-NAGPUR AND THE SONTHAL PARGANAS

35 The rivers of this group serve Western Bengal (the whole of the Burdwan division) and in the western portion of this tract they pass through a non-deltaic region. The problems presented for solution in this region, *viz.* those in connection with irrigation, are common to the rest of India and have already been dealt with. The eastern portion of the tract is deltaic, and due to human interference with the beneficent activities of the rivers traversing this portion, has given rise to problems which are unique and it is doubtful if a satisfactory solution can be found at all.

Unique problem presented by the embanked rivers in Western Bengal.

36. The area is flat and has been built up by the silt carried by these rivers of Western Bengal, particularly the Cossye in Midnapur district and the Damodar and the Ajay in Burdwan district But before the land could be sufficiently raised by such natural deposits it began to be reclaimed by flood embankments long before the British occupation. In those days, these embankments do not appear to have been efficiently maintained by the Zemindars and breaches were frequent Though this caused temporary inconvenience and damage, the land used to be flushed occasionally by silt-laden floods and the health and the productivity of the soil did not deteriorate to the same extent as at present The evil effects of these embankments were not of course realised in those days and for efficient maintenance they were gradually taken over by Government and improved with the object of preventing breaches as far as possible. In consequence, though the breaches are now less frequent and the protection enjoyed by the people is now more thorough, this very fact

has brought into prominence the evil effects of these embankments The land has been deprived of even the occasional flushing with silt-laden flood-water, which it was enjoying when these embankments were inefficiently maintained by the Zemindars This is not only causing progressive deterioration in public health and productivity of the soil but, being deprived of their source of sustenance, *viz* the river spills, the natural channels within the embanked area, have all badly deteriorated and the difficulty of draining these areas is becoming more and more acute

Premature reclamation by embankments responsible for present deterioration.

37. The embankments have thus prevented the gradual rise of the land by silt deposits during flood flushing. Indeed, it is actually becoming gradually lower, though at a very slow rate, due to the loss of the surface soil washed away by the rains. To make the case worse the floods, confined within embankments and unable to spill and deposit on the land as was intended by nature, are depositing a portion of the silt-contents within the river beds which are gradually rising The Irrigation Engineers in Bengal are thus faced with the most unenviable situation created by the low level of the land to be drained and the rise of the river beds into which the drainage has ultimately to be disposed of, and it has already become impossible to drain some areas by gravity As a direct consequence of embanking these rivers and preventing free spill over the countryside there was a considerable rise in the flood level soon after these embankments were constructed and this level is tending to rise higher and higher owing to the gradual rise of the river beds, necessitating higher and higher embankments to prevent overflow by the floods Indeed, during the Damodar floods of 1935 it was observed that, though the embankment was over 20 feet higher than the country level, at some places it was about to be overflowed, and this could be prevented only by raising the embankment during the progress of the flood. It is needless to say that breaches at such places would have been attended with disastrous consequences to the countryside owing to the terrific velocity which a wall of water over 20 feet high rushing out of the breach would have generated, sweeping away everything in its way—houses, cattle and even human beings.

Drainage difficulty gradually increasing.

Tendency of flood level to rise necessitating higher and higher embankments.

Sudden and concentrated discharge through breaches much more harmful than gradual inundation.

38. The potential danger to life and property that is likely to be caused by concentrated discharge through breaches at low places needs special mention and it is in such areas where high embankments have necessarily to be maintained, that breaches are more likely to occur In fact, there is a limit as regards depth of water which can safely be withheld by unprotected earthen bunds. At some places in the Damodar Embankment this limit has almost

been reached and, if the flood level rises higher, it will probably be necessary to go in for expensive surface protection of these embankments. But even then these earthen bunds can hardly be made breach-proof, for a little rat-hole may easily lead to a disaster; and where there are hundreds of miles of such embankments to look after, it is almost impossible to ensure that all such tiny holes have been detected and attended to in proper time In fact, such holes are usually covered by vegetation and can only be detected when the flood level has reached their river side ends, and if these ends are located high up the slope they may not be detected till the flood has risen very high, when it may be too late to do anything. In view of these difficulties occasional breaches in the unprotected earthen embankments and the consequent loss of life and property caused by concentrated discharge can hardly be avoided and it is surprising that they do not occur oftener than is the case at present

Occasional breaches in earthen embankments can hardly be avoided.

39. On the other hand what would happen if these rivers were left in their natural condition? The conditions now prevailing in Eastern Bengal furnish the answer No doubt there would have been flooding of the area now inefficiently protected by the embankment, but the flood being allowed to spill over the countryside, the depth of flooding would have been much less and it would be lower and lower as the land rose higher and higher by the silt deposit What I wish to emphasise is that there would have been no loss of life or property that is now caused by the high velocity of concentrated discharge through breaches. Moreover, there would be no distress among the people for, being accustomed to annual flooding, they would have erected their houses on mounds above the flood level, as is the practice in Eastern Bengal

40 The position is undoubtedly very serious and unless a bold policy of improvement is followed, this tract will, in course of time, revert to swamps and jungles from which it was prematurely reclaimed in the olden days. The ideal solution would be to remove the cause of deterioration, i e. the embankments, and raise the land and increase its productivity by allowing the flood water to spill and deposit the silt which is very rich in manure. Where possible this solution should certainly be adopted. Millions of tons of this valuable silt is now being carried away by the floods and lost to the country and the land, for which this silt was intended by nature, is starving. Above the tidal limits, where the water is sweet, such natural flood flushing need not necessarily destroy crops nor cause such acute distress amongst the people as is now being caused occasionally by the concentrated discharge through breaches in the embankments. For, when the embankments are removed, the flood level will also fall considerably lower, as compared with its present level, and as the floods in

Bold policy is needed.

The ideal solution.

Land is starving while its source of sustenance is being carried by the river floods into the sea.

these parts are short lived, lasting not more than 2 or 3 days at a time, such flooding may even be beneficial to the crops except in years of very high floods when, no doubt, the crops will be destroyed till these lands have been sufficiently raised by the silt deposit The loss, however, will be more than compensated for by the increased yield in normal years due to the manurial value of the silt and improvement in health As regards distress caused to the people by the collapse of houses it can certainly be avoided or at least minimised by erecting houses on earthen mounds and by avoiding mud walls, as is the practice in Eastern Bengal

Important vested interests come in the way of a bold policy being followed and controlled flood flushing seems to be the only practicable solution.

41 In most of the areas, however, owing to important vested interests such as the existence of railways, towns, etc, such uncontrolled flood flushing is hardly practicable and here we must be satisfied with limited flushing as may be found possible by drawing the flood water through regulated escapes to be built on these embankments It is quite possible to introduce such limited flushing in the area lying between the Cossye, the Selye and the Roopnarain rivers in Midnapore district and that lying between the Damodar, the Banka and the Hooghly rivers in Burdwan, Hooghly and Howrah districts For this latter area considerable progress has already been made towards the proposal of a flood flushing scheme A contour survey of the area was made a few years ago and the Government, on being advised that such a scheme is technically feasible, appointed a special officer to prepare an approximate estimate of cost This estimate has since been prepared and it was found during scrutiny that a mere flood flushing scheme, without provision to ensure irrigation in October, when rain and river supply both fail in these parts, though highly beneficial as regards improvement in sanitation and productivity of the soil, cannot ensure good harvest except in years of well distributed rainfall, and as such is neither likely to be popular nor financially sound Necessary orders were accordingly issued to make such provisions, i.e a storage reservoir in the upper valleys of the Damodar river and a Barrage across the Damodar near Burdwan. The rough cost of the combined flushing and irrigation scheme, including the above provisions for October irrigation, comes to Rs. 2,72,77,000 and it is intended not only to irrigate an area of 3,50,000 acres, where crops periodically fail for want of timely rainfall, thereby ensuring a good harvest in every year, but also to improve materially the sanitation and productivity of the soil by adequate flushing with the highly fertilizing silt-laden water of the Damodar floods. The next step is to prepare the detailed project estimate for which purpose one temporary Circle has recently been formed. The area proposed to be served by the project used to be one of the healthiest and most prosperous in Bengal, and though it has deteriorated to its present deplorable condition mainly by the acts of man, it is hoped that

Damodar flushing and Irrigation scheme.

human agency will again make it possible to retrieve the situation and to restore the area to its original condition of health and plenty.

42. It may be mentioned here that as soon as the evil effects of the embankments were realised the Bengal Embankment Act was passed In this Act there is an important provision making it a criminal offence to construct embankments, without previous permission, within certain areas which are being declared as prohibited from time to time. The area is, however, vast and enforcement of this provision, which involves frequent detailed inspection of the countryside and prosecution of the offenders, is proving rather a heavy burden with the very inadequate staff.

43. Even apart from the question of flood flushing, so necessary in the interest of health and productivity of the soil, the question of maintenance of these rivers is presenting problems of a more and more serious nature as the years pass. Considering the Damodar as a representative of this group of torrential rivers it may be mentioned that this channel near about Burdwan is barely sufficient to carry more than say 2,50,000 cusecs which represent its normal flood discharge. This capacity is again being progressively reduced due to the gradual rise of the bed in consequence of the marginal embankments and, in the lower reaches, owing to large quantities of silt brought in by the tides twice daily throughout the year, which the occasional floods during the rains cannot clear, it can hardly carry more than say 50,000 cusecs. The potential danger of a flood of the order of 6,50,000 cusecs as occurred in 1913 and 1935 rushing down this channel can easily be imagined.

Increasing difficulty in the maintenance of the Damodar in her present channel.

44. Originally the river was embanked on both sides but, appreciating this potential danger, the right embankment was abandoned towards the middle of the last century. This no doubt relieved the pressure on the left embankment for a time. But the right bank is also gradually being raised by the silt deposit with more and more pressure thrown on the left embankment and the time is not far distant when it will be impossible to maintain the left embankment, unless nature finds a remedy by cutting through the exposed right bank an escape into the Roopnarain, or it is provided by an artificial cut at a heavy cost. In fact nature appears to have already cut an escape in the Begua khal which is now carrying a considerable volume of the Damodar flood into the Roopnarain, but it takes off too far down the river and about 35 miles of the left embankment protecting a thickly populated area, including the town of Burdwan and the E.I. Railway line which runs very close to this portion of the embankment, is still being exposed to the full pressure of the Damodar flood, this is bound to increase more and more as the right bank and the river bed continue to rise by silt deposit.

Abandonment of the right embankment has not solved the problem.

45 If there were no flood embankments on either side as was intended by nature, the gain in elevation of the bank by silt deposit would at least have kept pace with the rise in the river bed as has been experienced in the case of the Nile It appears that the Nile was embanked only recently and that before then "during the Christian era while the matter deposited by the overflow of the Nile has raised the surface of Egypt by 4½ inches per century, the bed of the river has also been raised at the same rate" (Samuelson in his "Note on the Irrawadi river" quoted in Mr Reak's Report on Nadia Rivers) If both the embankments were retained, the country level on both the banks would have remained the same and though an avulsion would have been inevitable ultimately, owing to the gradual rise of the river bed and consequently of the flood level, it would have been left to nature to cut it either through the left bank towards the Hooghly or through the right bank towards the Roopnarain, probably the latter (as is evidenced by the natural formation of the Begua escape), owing to open country available on that side as compared with the left, where the country is full of obstructions such as E.I. Railway and G T Road embankments, etc The policy of abandonment of the right embankment and retention of the left, on the other hand, has resulted in the rapid rise of the country level on the right side, that on the left side has even probably been lowered by surface washing caused by the local rainfall The inevitable consequence, therefore, it seems to me, will be that nature will try to force an avulsion through the left bank towards the Hooghly unless we can take adequate remedial measures in the meantime.

Avulsion through left bank towards the Hooghly probable.

46. Such an avulsion will of course mean a serious disaster for, apart from the very large vested interests on the left bank which will be adversely affected, the important city of Calcutta and the large business interests on either bank of the Hooghly will be in great danger. It is no doubt true that till the middle of the 18th Century one of the Damodar outfalls was at Noaserai, a few miles above Hooghly town, but owing to desertion by the Damodar floods since then and by subsequent encroachments, the Hooghly channel has considerably shrunk and near about Calcutta it can hardly carry more than 3,66,000 (Mr. Reak's estimate in 1918 of maximum flood discharge) or say 3,50,000 cusecs in its present condition. The seriousness of the situation that will arise by the avulsion referred to above can, therefore, easily be imagined if it is remembered that in 1913 and in 1935 the flood discharge of the Damodar was of the order of 6½ lacs cusecs. Furthermore when the Damodar is in high flood it is very likely that the other western tributaries of the Bhagirathi also will be in high flood simultaneously owing to the proximity of their catchment areas.

Potential danger to Calcutta and the large business interests on the Hooghly.

47. The above consideration should rule out any proposal for remedial measures by means of uncontrolled escapes on the left bank, while as regards controlled escapes, it may be mentioned that the rough estimate which was recently prepared for flushing the decadent area on the left bank referred to before amounts to Rs. 2,72,77,000. The proposal provides for the extraction from the Damodar and distribution over the area of only about 13,000 cusecs out of the total maximum flood discharge of about 6,50,000 cusecs, a mere drop, which will not cause any material lowering of the flood level nor its pressure against the left embankment. To afford such relief we should extract something of the order of say about 2,00,000 cusecs. Apart from the prohibitive cost this extra discharge cannot possibly be carried by the Hooghly in the vicinity of Calcutta and above. Increasing the capacity of the Damodar channel by dredging does not also appear to be a feasible alternative. As I have mentioned already, apart from the question of cost, no river can permanently be maintained by dredging. This is all the more true in the case of the Damodar with such a wide range of flood discharge,—maximum flood occurring at long intervals—, and with the lower reaches liable to be chocked up by silt carried by the tides functioning twice daily.

Escapes through left bank not practicable.

Maintenance by dredging impossible.

48. As regards remedial measures the only feasible alternatives, therefore, seem to be either to construct flood moderating reservoirs in the upper valleys, probably the most satisfactory, though costly, solution, or to provide an escape into the Roopnarain through the right bank which should take off from a point as far above Burdwan as is possible. It seems to me that once upon a time, the Roopnarain probably constituted the outfall of the Damodar. The tendency of nature to restore the old condition through the Begua escape is not sufficiently helpful. We should help nature by taking off this escape from a point higher up the river. Along with the escape it is also necessary to improve the carrying capacity of the Roopnarain in her upper reaches by removal of some of the circuit embankments on her banks (Chetua and Mohankhally circuits, etc.) which, for reasons explained before, seems to be necessary even in the interests of the areas prematurely reclaimed by these embankments.

The only feasible alternatives.

Capacity of the Roopnarain.

Group III :—TIDAL RIVERS.

49. In their lower reaches these channels of groups I and II discussed above are tidal and, except where free tidal flushing of their spill areas has been interfered with by premature reclamation, their condition is not so bad. They are still continuing their beneficent activities mentioned above including the provision of cheap means of transport by water, a natural asset, which should be preserved at all costs. Mere

Tidal channels are valuable assets for purpose of communication and drainage.

tidal flow, unless reinforced by supply of upland water, cannot, however, maintain any channel for an indefinite period Tides in these parts carry a large proportion of silt with which nature is trying to raise the lower portion of the delta now deserted by the Ganges floods But it is only a question of time when the spill areas having been raised up to tide level, this silt, unable to spread over the land, will deposit in the channel bed in larger and larger quantities and will finally choke it. A gutter channel will probably remain for draining the local rainfall but the channel will no longer be fit for navigation.

Salt water limit is advancing up the delta.

Besides, with the reduction of pressure of sweet water from above, the salt water limit is also being pushed up these channels, and a serious situation is likely to arise if the upper reaches of these channels continue to deteriorate and the supply of sweet water is further reduced In fact, it appears that the salinity of the Hooghly water near Calcutta, on which this big city is dependent for its water-supply, is showing a tendency to increase during the dry season The case is probably similar or perhaps worse with regard to the tidal portion of the other spill channels in Central Bengal, as the only source of sweet water for these channels is the Ganges and from December till June they remain entirely cut off from this source, except the very small supply that is drawn by percolation through the sandy beds at their offtakes

50 But where free tidal flushing has been interfered with by premature reclamation of spill areas by means of marginal embankments, the situation has already become serious, and at several places owing to the deterioration of the tidal channels the difficulties of drainage are becoming more and more acute

Tidal channels not only serve the purpose of communication and drainage but are the only agency now left by which the lower portion of Bengal could be raised.

As mentioned already, apart from serving as carriers of country drainage with which we are all familiar, these rivers of Bengal, which are both upland flood carriers as also the tidal channels, perform the most important function of raising the delta we live in Owing to the diversion of the Ganges the upland flood carriers are no longer functioning in Central Bengal, and so tidal channels are the only agencies now left by which the lower portion of Bengal could be raised and made fit for human habitation. Another point to be noted is that when the upland flood carrier dies in a particular area, as for instance in Central Bengal, though that area suffers, its beneficent activities are not lost to the country, only these are transferred elsewhere. If, however, a tidal channel is obstructed it usually gets choked in its own bed without any chance of diversion by avulsion as the energy required for the purpose is lacking, it not being possible for a tidal channel to rise above the tide level.

Death of a tidal channel is a permanent loss to the country.

Thus the consequence of premature reclamation by marginal embankments or other obstructions in tidal channels is that their beneficent activities of raising this portion of the delta will be lost to the country for ever and the land will continue to remain

low with increasing difficulties of drainage until it becomes unfit for human habitation and reverts to swamps and jungles We have instances of this almost next door to Calcutta, *viz.* the low areas served by the Bidyadhari which, owing to earlier reclamation of the spill areas, is now completely dead and can no longer serve as a carrier of drainage, with serious consequences to the city of Calcutta and suburban areas. The Peali is also fast dying and will probably share the same fate as that of the Bidyadhari unless steps are immediately taken to throw open sufficient spill areas for this river.

Supply of upland water essential for preservation of tidal channels permanently.

51. In fact the provision of spill areas by the removal of marginal embankments seems to be an urgent necessity for prolonging the life of these tidal channels. But this is not enough. If these channels have to be given a permanent lease of life the supply of upland water seems to be an essential requirement. As this point is not usually understood it seems necessary to explain the physical characteristics of tidal rivers.

52. The energy which creates the tidal flow, *viz* the attraction of the sun and the moon in the sea is very limited and is manifested partly as potential energy, *viz.* rise in tide level, and partly as kinetic energy, *viz.* velocity of flow. The former causes the tidal flow up the rivers and the latter determines its power of transporting silt. As the velocity of the tide when it enters the mouths of these tidal rivers is high and as there is a vast reservoir of unconsolidated silt in suspension along the delta face, the tide as it flows up these rivers is highly charged with silt. It is generally observed that the duration of ebb tide in a tidal river is much longer than that of the flow tide. As the same quantity of water must ebb out as flowed in, it, therefore, follows that the average velocity of 'ebb' is less than that of 'flow'. Now the capacity of water to transport silt depends on its velocity. Consequently the ebb tide is generally unable to carry back all the silt that has been carried up these tidal rivers by the 'flow tide'. Even a slight deposition of silt will add to the accumulation as the tides function twice daily throughout the year and the channel will begin to deteriorate The deterioration would impede the propagation of the tidal wave which would cause further deterioration and the vicious circle would continue till the channel is completely dead.

53. It will appear from the above that to maintain the life of a tidal river what is necessary is an additional supply of water not saturated with silt, *i.e.* which has the reserve capacity to pick up more silt, to supplement the tidal flow during ebb so as to scour out fully the silt that has been admitted into the river by the flood tide. This could be effected either by the supply of upland water, local drainage, or by throwing the existing spill area open to the daily ebb and flow or by adding new spill areas, if possible. The spill area is of course an important flushing agent but it would function only for a limited period at a gradually diminishing rate, till the whole area is raised to high water level and its storage capacity is reduced to nil. The local drainage would

also be specially helpful, while crops are standing in the fields, as the water at such time would be practically silt-free But this agency can function only during the rains, and for 7 months (November to May) no material contribution can be expected from local drainage, however large the drainage area may be, to help in flushing the river during ebb The third agent, *viz* upland water, is certainly the most important and if it were possible to arrange for its supply perennially, so as to flush the river even during the dry season, there is no reason why a tidal river should not live and continue her beneficent activities for a great length of time

54 Improvement of the spill channels of Central Bengal and diversion through them of a portion of the Ganges flood thus appear to be necessary even in the interest of the tidal portion of Central Bengal as this water, after spilling over the land and depositing the silt content, will have to pass through these tidal channels for disposal into the sea With the help of a copious supply of sweet water, it will be possible not only to maintain these tidal channels permanently but also to push down the salt water limit and extend cultivation more and more towards the sea-face even without embankments, as is the practice in Eastern Bengal

Bidyadhari river.

55. In recent years the Bidyadhari river has been very much in the public eye owing to the increasing difficulty that is being experienced in disposing of the drainage from Calcutta through this outfall I, therefore, propose to take up this river as a typical representative of this group and briefly review its life-history to illustrate the points discussed above

56 As discussed in dealing with the Primary delta builders of Group I, the Jamuna, before the diversion of the Ganges flood through the Padma, constituted one of the main branches of the Ganges Separated off at Tribeni the flood used to flow down this stream to the sea In fact, between the Bhairab and its branches to the east and the Hooghly river to the west, the Jamuna was perhaps the most important delta builder in those days, and largely contributed to the raising of this portion of the Sunderbans. The Bidyadhari was an important spill channel of the Jamuna and to her was allotted the task of raising the delta just to the east of the areas near about Calcutta. Channels connecting the Bidyadhari with the Jamuna in the olden days (Nowi, Sunti and Nanagong) can still be traced reaching within a few miles of the present abandoned course of the Jamuna.

Bidyadhari was a spill channel of the Jamuna and carried her share of the upland flood when the Jamuna was active.

57. But the most indisputable evidence that the Bidyadhari used to receive a considerable supply of upland floods is afforded by the width[1]

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[1] The width varies from 360 ft. to 900 ft, the average being 660 ft and the level of the bank from 10 21 to 16·66, the average being 12 57 ft within a length of about 10 miles above Bhangore canal As compared with this the highest tide level recorded at

between the high banks of what is now called the Bidhyadhari khal just above Bhangore canal. In fact I was surprised to find such high natural banks in the midst of what was known to be a purely tidal area when I inspected the khal in 1933. I had several cross sections taken to ascertain whether they were really above the high tide level as that would prove conclusively that the Bidyadhari used to receive upland floods As the cross sections show, these banks are much above the high tide level even of the present day (which must be considerably higher than when the river was allowed to spill freely over the banks), and they could not have been built up by the tidal silt but must have been raised by the silt carried by the upland water. Having regard to the characteristics of delta builders of which the banks slope away from the river edge, the width between the crests of these high banks, therefore, gives a rough measure of the extent of upland flood supply in the olden days and, judged by this standard, it must have been considerable.

Indisputable evidence left by nature in her bank levels which are much higher than the tide levels.

Width between crests of banks gives a rough measure of her old prosperity.

58. I would particularly emphasise the importance of this method of reconstruction of the life-history of deltaic rivers by means of cross sections. After completion of the contour survey of Central Bengal, portions of which have already been surveyed, we should have a lot of data to help us in this direction. For instance from cross sections of the country round about the Saraswati I found that this river, which now looks like a gutter, was originally a big river, thus corroborating the view that the Saraswati was a branch of the main Ganges as there is no other delta builder on this side of the country which could throw a branch of this size.

Field for research in reconstructing the life-history of rivers in Deltaic Bengal.

59. By similar evidence left by nature it was also found that the Kultigong, which now constitutes the outfall of the Nowi, Sunti and Nanagong (formerly feeders of the Bidyadhari), probably opened up much later than the Bidyadhari. In any case it was originally a channel of minor importance as compared with the Bidyadhari. Measured from the present outfall of the Nanagong into the Haroagong (the connecting channel between the Kulti and the Bidyadhari) high banks much above the high tide level extend to only a little over 6 miles along the Kulti route, while along the Bidyadhari they extend to at least 14 miles. I have discussed these points at length in my official report on the 'Bidyadhari Restoration scheme' and it will unduly

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Bamanghata on the Bidyadhari, which is progressively rising, was 10 33 and the average High water 8 8 in 1932 At Haroa (a short distance above the length considered) the H H.W. and the average H.W. level in 1932 were 11 0 ft. and 8 75 ft. respectively.

All levels referred to are taken on O.M.S.L. or P.W.D. datum.

lengthen the size of this paper if these evidence and arguments are reproduced here. I shall merely summarise the conclusion that I arrived at after a critical analysis of all the available evidence.

Life-history of the Bidyadhari river reconstructed.

60. So long as the Jamuna remained active the Bidyadhari used to get a considerable supply of upland water (including a portion of the dry weather flow of the Ganges), not only the flood carried by the Nowi and Sunti, but also the major portion of the flood carried by the Nanagong Deterioration of the Jamuna probably set in soon after the diversion of the main volume of the Ganges flood towards the end of the 15th Century or early in the 16th Century. It seems probable, however, that it still continued to receive, at least during the rains, a share of the Damodar flood, which had one of its outfalls into the Hooghly near Kalna until about 1660 and near Noaserai until about the middle of the 18th Century, both the places being above the offtake of the Jamuna at Tribeni Diversion of the Damodar down its present channel with its outfall below Uluberia at the latter date finally sealed the fate of the Jamuna which, together with the spill channels, began to deteriorate rapidly.

61 Deprived of the upland water supply, the Bidyadhari was then thrown entirely on her own resources, *viz* local drainage and spill area to prolong her life as long as she could At this stage another characteristic, peculiar to tidal rivers carrying a large proportion of silt, hastened her decay

Stoppage of upland water supply and meeting of tides—natural causes of deterioration.

The Kultigong, the next parallel tidal channel to the east, had already opened up and by means of the connecting channel, now known as the Haroagong, provided a meeting ground for tides coming up both this river and the Bidyadhari Owing to check in velocity there is always a heavy deposition of silt at the tidal meeting ground, but so long as these rivers received a plentiful supply of upland floods, this silt could be cleared by flushing during floods. After the stoppage of this supply, the silt deposited as a result of the meeting of the tides became a grave menace to the preservation of both the channels Nature had thus to sacrifice one for the preservation of the other. It seems to me that by this time the Kultigong, which was originally discharging into the Matla through Kumerjolgong, had her present outfall into the Roymangal Estuary definitely established. Now the Roymangal is one of the deepest estuaries in the delta and the conditions for the propagation of the tidal wave being more favourable, the stronger tide up the Kultigong could travel higher and higher up the connecting channel (Haroagong), thus shifting the tidal meeting ground more and more down the Bidyadhari. The Nanagong, the Sunti and the Nowi, which originally used to feed the Bidyadhari, were thus gradually absorbed by the Kultigong for her own sustenance. By robbing the Bidyadhari of the drainage and spill areas of these feeders, the Kultigong thus began to develop at the expense of the Bidyadhari and the latter river deteriorated rapidly

62. But though the fate of the Bidyadhari as a permanent channel was thus sealed, the existence of a large spill area in the salt lakes should have made it possible for her to function as an outfall for the drainage from Calcutta and the neighbouring areas for a much longer period but for the acts of man. The salt lakes, even after reclamation along the borders now measure about 55 sq. miles and, it seems to me, define the boundary between the area built up from the north by the upland floods and that from the south by the tides carried up the Bidyadhari and the Peali. Even after the stoppage of upland floods it should have been possible for nature but for human interference, to raise this area by tidal deposit instead of leaving it as a nuisance so close to the city.

Death of the Bidyadhari hastened by the acts of man.

63. The first interference was the premature reclamation of the land on either bank of the Matla and of the Bidyadhari by means of marginal embankments, towards the middle of the last century This was one of the earliest areas to be reclaimed, and consequently both the channels began to deteriorate with progressive rise in tide level or what may be called 'heaping up of tides'. At Port Canning (Bidyadhari outfall into the Matla) the highest high water level has risen from 6 28 in 1865 to 12 83 in 1930 (O M S L. data). At Dhappa the ordinary high water level in 1830, as gathered from old records, was 1·5 in the dry season and 3·5 in the rains. The H.W. level was 9 41 in 1926. At Bamanghata on the Bidyadhari the H.H.W. level has risen from 9 1 in 1894 to 11·00 in 1926 It will be of no use referring to the level at Dhappa and Bamanghata in recent years as tidal flow is practically non-existent and the level is really ruled by the discharge of Calcutta drainage, but it may be noted that the present level is considerably higher. The Bidyadhari, which hitherto used to drain Calcutta, is now trying to drown the city with the sewage and we are trying to prevent the catastrophe by means of flood embankments proposed to be constructed along the eastern boundary

Rise in tidal level—an inevitable sign of deterioration.

64. Now this 'heaping up of tides', which occurs when a tidal wave is unable to dissipate itself over the spill area, is another characteristic of tidal rivers, and where tides carry a large proportion of silt, as in Bengal, it causes deterioration of the channel by the dropping of silt. The explanation is probably as follows: 'Heaping up' of tidal flow really means gain in potential energy But as the sum total of the energy which generates this flow, *viz.* tidal impulse created in the deep sea by the attraction of the sun and the moon, etc. is constant during each tide, this gain in potential energy must be attended with a corresponding loss in its kinetic energy, or in other words the flood tide can only rise in level at the expense of its velocity. Now the silt-carrying capacity of the flow being proportional to the velocity, it follows that

Significance of 'heaping up of tides' explained.

as soon as 'heaping up' occurs a portion of the silt brought up by the tides, in excess of what the reduced velocity can carry, drops on the bed, thereby further impeding the tidal wave and accelerating the deterioration of the channel in a vicious circle. This phenomenon of 'heaping up of tides' is going on more or less in almost all the tidal rivers, where the spill area has been unduly curtailed and really constitutes the preliminary warning of deterioration. In the Bidyadhari, and at the head of the Matla Estuary, the 'heaping up of the tides' is probably the worst as their spill areas have been the earliest to be reclaimed It becomes less and less as we move towards the eastern parts of the delta

65 The second stage of human interference was the discharge of the Calcutta sewage into the Bidyadhari While the liquid content has probably been helpful, especially during the dry season, the solid matter has certainly been harmful specially by forming a gelatinous coating over the channel bed and slope which the ebb flow finds it difficult to scour. The large number of fisheries in the salt lakes and other low areas also contributed to the deterioration of the Bidyadhari by preventing free tidal spill Finally, the Kristopur canal (excavated in 1910), by cutting off a good portion of the salt lake spill area (Ghuni Jatragatchi—about 18 sq miles) and interfering with the natural drainage from the north, accelerated the death of the Bidyadhari

All attempts for revival of the Bidyadhari have failed.

66. Attempts were made to revive the Bidyadhari both by acquiring a spill area (about 2½ sq miles which was found to be much too small) and also by dredging at a heavy cost But the opposing forces were found to be much too strong and the Bidyadhari continued to deteriorate She is now absolutely dead without any chance of revival and it would be interesting to note the rapid rate of deterioration from the following figures —

	1883.	1904.	1936
Lowest Bed level near Bamanghata referred to O.M S L or P W D datum	−58·69	−29·71	+5·75

The present bed is even higher than the country level on either side

	1894	1915.	1917	1926	1932.	1936.
L.L. water level at Bamanghata ..	−4·9	0·0	+0·17	+2·5	+5·92	+11·05

	1926	1936.
Cross sectional area at Bamanghata below R.L 9·75	2,440 sq. ft.	363 sq ft.

67. All attempts at the restoration of the Bidyadhari have now been rightly abandoned and the Calcutta Corporation are dredging an independent outfall into the Kultigong As the proposal has received the approval of Government and the work is in progress I refrain from making any comments.

Nor would such comments be really appropriate in the present paper, which only deals with river problems in general and does not aim at finding a solution to any specific local problem like the drainage problem near about Calcutta. This problem is sufficiently important and complex to form the subject of a special paper. I wish only to add in this connection that the Peali, a branch of the Bidyadhari, is also fast deteriorating and will soon share the same fate as the Bidyadhari. Immediate steps are, therefore, necessary to prolong the life of this river. After the death of the Bidyadhari, the Peali is now the only source of drainage for a large portion of 24-Parganas district and constitutes the outfall of several drainage schemes constructed by Government at a heavy cost. The death of the Peali will not only mean the loss of this capital but, due to consequent water logging, the area affected will gradually revert to swamps and jungles from which it was prematurely reclaimed by the acts of man.

Life of the Peali must be prolonged in the interest of drainage of a large area.

RIVER PROBLEMS WITH REFERENCE TO NAVIGATION.

68. I have dealt with the river problems in Bengal so far as they have arisen in respect of the beneficent activities of the rivers in draining and fertilising the land which they have created. I now refer to another aspect of river problems in respect of the valuable services which the rivers are rendering to the country in the matter of carrying the produce by cheap water routes. Together with the tidal portion of Central Bengal, Eastern Bengal possesses very important natural resources in her navigable channels, the value of which in promoting trade and providing facilities for cheap communication can hardly be exaggerated. We have first the principal highways, *viz.* the Ganges, the Brahmaputra and the Meghna, providing water communication with the neighbouring provinces of Bihar and Assam. Then we have the network of feeder channels connecting these main waterways with the trade centres including Calcutta, one of the important ports in the world. Again, in Eastern Bengal, which is inundated by the floods of these rivers, it is possible during the monsoon to carry goods by water practically from every village to the nearest feeder channel, and from there to one of the principal highways for transport to the several trade centres. This is perhaps unique in the history of the world, for, though there are other countries possessing natural waterways, I do not know of any where the system of internal boat communication has been so thoroughly planned by nature as in these parts. Apart from its value to trade it is also providing employment to hundreds or thousands of people, the importance of which in a province like Bengal, where the pressure of population is already being felt, can hardly be exaggerated.

Waterways constitute a valuable natural asset.

69. The importance of conserving and improving, where possible, this valued gift of nature is, therefore, obvious As regards the principal highways no attention is really needed except during the dry months, when it may be necessary, near bad shoals, to train and divert the available flow through particular channels so as to increase the depth of water to suit the requirements of navigation. A large quantity of the discharge of the Ganges and her tributaries is, however, being utilised for irrigation in the upper provinces and so long as it is extracted during the monsoon months, it does not seriously matter as there is plenty to spare But further extraction of low water discharge of these rivers should be a matter of serious concern to Bengal and Bihar as not only is this likely to endanger navigation in the Ganges during the low water season, but, after the improvement of her spill channels in Central Bengal, we shall require more and more of this discharge to pass through them to keep them efficient It, therefore, seems necessary to keep an eye on the future development of irrigation schemes in the Ganges basin in the upper provinces and, as the interests of these provinces are likely to conflict with those of Bengal, the necessity for the establishment of a representative body to adjudicate those interests has to be considered

Conservancy of waterways—the pressing need for Eastern Bengal.

Further reduction of low water discharge of the Ganges—a matter of serious concern to Bengal.

Necessity for an interprovincial River Commission.

70. But the main problem which we have to face at present in the matter of improving facilities for communication by water is with regard to the feeder channels connecting these principal highways, especially with Calcutta In the olden days, when the Bhagirathi was in better condition, Calcutta was of course directly connected by water with the Ganges. Later, as navigation through the Bhagirathi became more and more difficult, the Jalangi and the Mathabhanga were being utilised for the purpose In those days steamers were of course unknown and, as can be gathered from the old records, navigation even by boats was difficult during the dry months. It appears that even up to about the middle of the last century there was considerable activity in connection with attempts made to maintain the Mathabhanga as a feeder route to Calcutta from the Ganges. (*N B.* :—The Churni connecting the Mathabhanga with the Hooghly appears to have been an artificial cut made in the interest of navigation)

Maintenance of feeder channels constitutes the main navigation problem.

Most of the supply drawn from the Ganges by the Mathabhanga offtake was in those days escaping into the Kumar and steps were taken to prevent this by artificial action It also appears that in 1860 and 1861 five chord cuts were made across some of the bad loops of the Mathabhanga thereby shortening the river by 21 miles and making its fall equal to that of the Kumar.

71. These attempts, however, did not prove very successful and more and more attention was paid in improving the boat route through the

Sunderbans. The construction of Calcutta Canals including the Chitpur lock was taken up early in the 19th Century and the canal route was gradually improved by the construction of New cut canal in 1859, Dhappa, Bamanghata and Kulti locks in 1895, and lastly the Kristopur canal in 1910, which was intended for boats When steamers were introduced later, they used to enter the Bidyadhari through Tolly's nalla (excavated in 1770) and take the Sunderban route *via* Port Canning and Matla. Owing to the deterioration of the Bidyadhari and the Matla the steamer route is being gradually shifted more and more towards the sea face. Here again nature has helped us by providing cross connections between outfalls of primary delta builders (estuaries), usually flowing north to south. But for these cross connections navigation from Calcutta to the Ganges would have been difficult by steamers and probably impossible by boats, as they would have to pass out into the sea to get into the next north-to-south channel and so on In fact our main problem at present in respect of navigable waterways is with regard to the maintenance of these cross connections. The maintenance of the north-to-south channels is also proving more and more difficult and will be impossible ultimately, as these channels, in the absence of upland water supply and with spill areas prematurely reclaimed, continue to deteriorate as in the case of the Bidyadhari and the Matla.

Cross channels —valuable natural gift.

Their maintenance constitutes the main navigation problem.

72. The existence of these cross channels is probably attributable to the funnel-shape of the Bay of Bengal, the deepest sea being in the middle ending in the 'Swatch of no ground', more or less in a line with the centre of the delta and the shallower and shallower sea running along the coast lines to the east and west. Owing to the more favourable conditions available for the propagation of the tidal wave along the deeper or central portion of the Bay, the tide makes first at the head of the 'Swatch of no ground' and travels along the delta face, one branch running to the west and another to the east. For this reason and also due to the irregular extension of the delta as pointed out above, the tides do not make absolutely at the same time at different points in the same latitude along the delta face, thus giving rise to cross currents between the deeper channels just below the outfalls of contiguous north-to-south delta builders. As pointed out by Major Hirst (*Report on Nadia Rivers*, 1915) the delta, in consequence, has not probably extended continuously but in the shape of islands between two contiguous outfalls, leaving a cross channel between the island and the main land. So long as the difference in the time of arrival of the tide at either end was such as to prevent the formation of a tidal meeting ground within the cross channel, it remained. But where, owing

Origin of cross channels explained.

to irregular extension of the island at its outer face, due probably to one delta builder being more active than the other, this difference was altered so as to provide a tidal meeting ground within the cross channel, it closed up, joining the island with the main land. In this way many of the cross channels have now disappeared throwing the steamer route more and more to the sea face. The gradual rise of the tide level with a tendency to drop a larger and larger proportion of the silt content has also helped in this process.

Meeting of tides—a grave menace to the maintenance of cross channels.

73. It has been stated above that, along with the improvement of the rivers in Central Bengal in their upper reaches and diversion through them of a portion of the Ganges flood, their tidal reaches will also automatically improve and with the copious supply of upland water thus available a solution may be found to maintain these tidal channels on a permanent basis which is so vitally necessary in the interest of inland navigation in Bengal.

74. In this connection it may be mentioned that to shorten the distance by water between Calcutta and the Ganges, the *Madaripur Bil Route* was opened early in the present century. As the name indicates, it was a passage about 20 miles long cut through a series of *bils* connecting the Madhumati at Manickdah with the Kumar river at Fatehpur and through that river and the Ariel Khan with the Ganges. The scheme was highly successful as the spill of the Ganges and the Madhumati, after depositing the silt on the *bils* and the country-side lying to the north and west of these channels, was sufficient to give them a thorough flushing and they were more or less self-maintaining. This route practically monopolized the whole volume of waterborne traffic between Calcutta and Bihar and Upper Assam and, apart from immense benefit to trade, it was also yielding a decent revenue to Government. But to meet the demand of the growing heavy traffic it was considered necessary to widen the bil route which, in consequence, began to draw more and more of the available spill supply at the expense of the Kumar which, for want of sufficient nourishment, is now being starved to death and in which navigation is no longer possible during the dry months. It is a highly complicated subject and cannot be dealt with properly in a short note. But I mention it to show that in this case also we have the requisite natural resources in the large volume of flood water now running to waste in the Ganges and the Madhumati and the problem is one of diverting a portion to feed the Kumar which is starving to death for want of an adequate supply.

Difficulties in the maintenance of the Lower Kumar river—cross connection between Madhumati and the Ganges.

75. While dealing with this subject of communication, I should like to sound a note of warning especially to those who live in areas which are still being favoured by nature in the shape of annual flood flushing. We hear talk of the extension of railways in those parts, for instance the rail road from Barisal to Madaripur and between Dacca and Aricha, etc. The improvement

of facilities for communication is certainly necessary as these are vital factors in the cultural and economic uplift of a nation. But rail roads in these parts have to be carried on high embankments, materially interfering with the flushing arrangement devised by nature. We should not, therefore, repeat the mistakes made in the case of Western Bengal and, instead of embanked roads or railways, our policy in future should rather be to meet the demand for communication in these parts by improving the existing waterways and making new waterways where none exist at present.

River problems with reference to erosion.

Erosion problem—inherent in the conditions of flow of deltaic rivers.

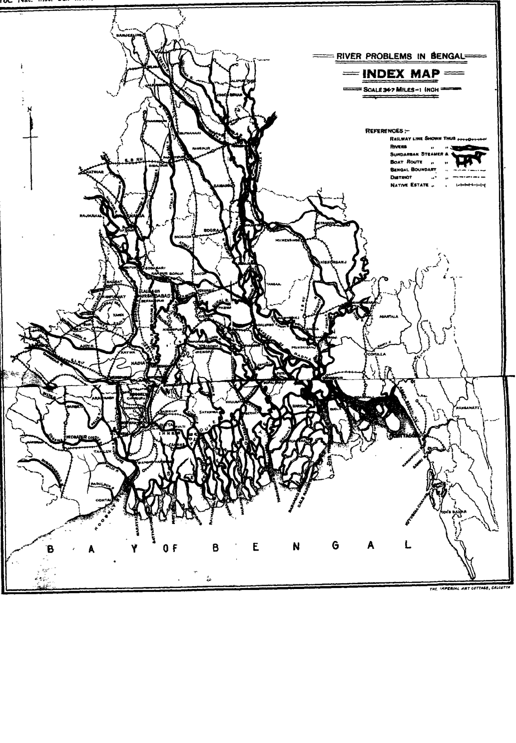
76. Another problem that I should like to mention before I conclude is what is being created especially by the primary delta builders of group I, in Eastern and Northern Bengal, by the rapid erosion of the banks. The problem is to a certain extent inherent in the conditions of flow of deltaic rivers, but it has been aggravated by the natural tendency to concentrate all available flow into the two principal rivers—the Ganges and the Jamuna. Resuscitation of the rivers in Central and Northern Bengal, so as to enable them to carry their due share of flood water, will no doubt make the position somewhat easier, but the erosion will still continue to remain a problem as the soil through which these rivers flow is extremely soft. Special study in a laboratory may perhaps reveal some cheap method of river conservancy by which this problem can be satisfactorily solved. But the method of direct action, *viz.* the protection of the eroding bank by brick mattress, etc. that is now followed, is so very costly that it can hardly be adopted except for the protection of important towns.

Silt factor dominates the river problems in Bengal.

77. It will be seen from the above that the all-important factor which dominates the river problems in Bengal is the large proportion of silt carried by the floods It is the silt which has created the land and made it habitable by raising it through centuries It is the silt again which is fertilizing the land, and where the process is still operating the country is healthy and prosperous, while where it has ceased to function the country is progressively deteriorating in health and productivity of the soil. But though the silt has proved to be such a beneficial gift of nature this very factor has given rise to most of our river problems that we find to-day. It is the silt which, by deteriorating the old river channels, has forced their diversion through lower areas which, though beneficial to the latter, has been so harmful to the area served by the former as we have seen in the case of Central and Northern Bengal. It is the silt which, by raising the beds and consequently the flood level of embanked rivers, has created problems highly complex and unique in character, as we have seen in the case of the rivers of Western Bengal, especially the Damodar. It is the silt which has killed

many of the tidal rivers in Central Bengal and threatens to kill the rest with disastrous consequences to the interests of navigation and drainage, unless we can reinforce the ebb flow in her struggle against the silt brought in by the flood tides. It is the silt again which is killing the cross channels so valuable in the interests of navigation, which, like a thoughtful mother, nature left between the north to south channels for the benefit of Bengal in the process of extending the delta Silt, in short, is one of our greatest benefactors and, in some respects, also a malefactor and we ought to make the closest study of this all-important factor Unfortunately we possess very little information on the subject beyond the general knowledge as indicated above What is required is a fully equipped laboratory to study this and other questions amenable to laboratory treatment, thoroughly and scientifically, and to guide us in our effort to solve the rather complicated river problems in Bengal Many of these problems are rather unique and without parallel The results achieved elsewhere will not help us much, we have to find the solution ourselves by long and concentrated study of local conditions.

Necessity for research.


RIVER PROBLEMS IN BENGAL
INDEX MAP
SCALE 34·7 MILES=1 INCH
REFERENCES :-
RAILWAY LINE SHOWN THUS
RIVERS
SUNDARBAN STEAMER & BOAT ROUTE
BENGAL BOUNDARY
DISTRICT
NATIVE ESTATE
B A Y OF B E N G A L
THE IMPERIAL ART COTTAGE, CALCUTTA

RIVER PHYSICS LABORATORIES OF EUROPE AND AMERICA.

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(Read at Symposium, January 9, 1938.)

Of recent years conviction has been gaining ground among hydraulic research workers that there is a physics of river flow and as such it is possible to study river movements and the changes in the course of a river from scale models in a laboratory Though the science of River Physics has not attained to that stage of development as has been reached by the science of Nuclear Physics or any other branches of Physics, yet since the days of M Fargue, Osborne Reynolds and Vernon-Hercourt the progress of this branch of Physics has been very rapid The experiments of Prof Gibson in England, of Engel, Winkel, Krey and Rehbock in Germany and of Freeman in America have proved conclusively that not only can scale models, properly conducted, give valuable indications for training of a river, quantitative information can also be obtained from such experiments In his tidal model of the river Severn, Prof. Gibson has been able to reproduce the conditions of the river in 1927 starting with the river in 1848. Prof. Krey in his Elb model and Prof. Rehbock in the Rhine model have been able to get very good quantitative agreement between the model and the prototype In the U S Waterways Experimental Station at Vicksberg, Vogel has been able to reproduce various conditions of the river Mississippi in a number of models.

It will be interesting to compare the various methods applied by different workers in developing their river models and also the amount of success they have attained in them.

Prof. Gibson's name is mainly associated with the tidal model of the river Severn. He has made this model a complete success. His method of working can be summarized as follows:—

The model was moulded in Portland cement supported by a wooden tank having the internal dimensions shewn in Fig. 1 For moulding the model a series of equidistant parallel cross-sections (138 in all) of the estuary and the surrounding district included within the boundaries of the tank were drawn on mill-board, data being obtained from the 1848 survey. These were cut and mounted vertically in the tank and were used as templets Where rocks are marked in the charts these are moulded to the correct height. Where the soundings show gravel, clay or hard sand, this was reproduced by a cohesive mixture of Leighton Buzzard sand and a very fine silica sand containing a proportion of China clay. Where the charts showed a sandy bottom the cement bottom of the model is moulded at such a depth as to allow of the equivalent of at least 10 feet of sand in the upper reaches and from 30 feet

to 40 feet in the lower reaches of the estuary and sand was afterwards filled in to the correct depth.

The tides were produced by the rise and fall of a plunger in a tank forming a continuation of the seaward end of the model. This plunger was operated

from a mechanism driven by a 2 h.p. induction motor. The correct tidal period in the model was calculated from the following relationship:—

$$t = T \frac{l}{L} \sqrt{\frac{H}{h}},$$

where capital letters refer to prototype. So that with a scale ratio 1/100 and 12 hr. 20 minutes as the tidal period in the prototype the tidal period in the model was kept at 52·23 sc.

One of the first requirements was to determine what size of sand would reproduce most accurately the conformation of the bed of the estuary and experiments to this end were carried out on both models after which the original programme was followed using this sand.

Owing to the fact that fine silt, such as is found in the Severn Estuary, becomes coagulated and settles much more rapidly in sea water than in fresh water it was necessary to reproduce this effect of the sea water in the model. For this it was decided to make use of the coagulating properties of a weak solution of alum. The alum was made up into a solution and fed into the model.

The results obtained by him are best expressed in his own words:—

'On the hydrodynamical side—the reproduction of currents, water-levels, tides and wave-motion—a suitable model is capable of giving results which

may fairly be claimed to be accurate within the limits of experimental investigation.

The question as to how nearly quantitative agreement is to be expected regarding the movement of bed-materials, erosion and deposition is not so easy to answer. We know that training works, bridge piers and other structures affect the set and velocity of the currents to an extent and in a manner which is reproduced with close accuracy in a suitable model Inasmuch as an increased velocity causes scour and a reduced velocity causes deposition, if the bed-material is moved the movement caused by the change will be in the same general direction and of the same kind as in nature, so that it is to be expected that the same kind of configuration will result

Much depends on how far it is possible in a model to reproduce accurately all the factors involved. The final answer to the question can only be given when we have available the results of many model tests and corresponding results under similar conditions in nature, and until then caution must be used in predicting quantitative results.'

He concludes with the remarks:—

'I think it is not overstating the case to say that in expert hands such models are capable of giving results whose interpretation enables quantitative values to be pre-determined with sufficient accuracy for most practical engineering purposes'

Prof Krey of Berlin had carried out a long series of experiments on the river Elb His method can be summarised as follows —

The model was built on a platform 4 m wide and 18 m long The platform rested on the adjustable support of the small flume, so that if found necessary afterwards the slope of the model could be varied by lowering one end of the platform. The outlines of the platform are shown by dotted line in Fig 2. Projecting berms that in nature are kept in position by the growth of grass were formed in the model by sand and consolidated by milk of cement. Besides this the model river bed in the river channel and between the dikes consisted of fine moveable sand as in nature This was laid to such a depth that every possible bed movement in nature could be reproduced in the model

In order to reduce the error due to either of these two alternative methods in the experiments (distortion of the vertical scale or increasing the slope by tilting the platform) both the methods were combined. Thereby it was possible to deviate very slightly from geometrical similarity both in depth and slope. The error was rendered smaller by this method than what would have been the case if one had to obtain the tractive force necessary for the maintenance of silt movement in models either by increasing the depth or by steepening the slope.

The conclusions arrived at by him can be briefly indicated thus:—

Definite rules cannot be set up for the selection of the time scale as the time that is required for the formation of the bed in the model depends on the model scale ratio, the model sand and also on the particular problem. The

time scale, therefore, should be determined beforehand according to the requirements of the experiments. It has, therefore, been the practice in the Institute

FIG. 2.

since 1928 to start the experiments on a bed with uniform slope and horizontal cross-section and to allow the model discharge to work out its own bed formation. The discharge was so selected as to give the required gauge readings of the prototype for a year or a number of years, at the end of this period a definite bed formation used to be attained. A comparison between the model bed formation and the prototype allowed an idea to be obtained about the correctness of the time scale selection. The model or one of the scale ratios must be altered if the reproduction of the bed formation is not complete within a reasonable model time scale

The most important of the river models of Prof. Rehbock of Karlsruhe was that of the Rhine. This work he did for the Rhine River Commission His general principles of river experiments are as follows. When it is decided to do model experiments on a stretch of a river a long stretch of the river is taken and 2 or 3 different models with different scale ratios are constructed, say 200 : 1, 160 : 1, 150 : 1, the length ratio and the depth are the same. Having thus fixed the scale ratio the discharge is consequently fixed. The river is then built with its levee that has remained stationary for a considerable length of time. The bed of the model which has a different slope steeper than that of the river is filled uniformly with brown coal—very light chips of coal about 1 to 1·5 mm. in size and density about 1·4—to a certain depth. A certain discharge is allowed to pass over the model for different lengths of time and the contours traced out by the water are photographed by a camera that travels on two rails at a height of about 2 or 3 m: above the model, the rail

is kept parallel to the water surface so that photographs of the same size are obtained every time. These contours are then obtained for different discharges and then compared to the actual contours of the river bed: by this means a time factor for each experiment is obtained which is different for different rivers This time factor depends on the slope and the quality of silt used. For a stretch of the Rhine, Prof. Rehbock has found that for the scale ratio 160 : 1 the time factor 61 is nearly correct and that a change that took 2 years in the Rhine to take place will require less than one day in the model

Vogel's experiments on models of the river Mississippi are very interesting and show what can be attained in such experiments with proper care and judicious handling of the model.

A number of model results on the Mississippi carried out at the U S. Waterways Experimental Station, Vicksburg, Miss , U.S A., are quoted by Mr. H. D. Vogel in a paper entitled 'Hydraulic Laboratory Results and their Verification in Nature'. He gives instances of the following models :—

1. The Brooks Point Model.
2. The First Charters Model
3. The Point Pleasant Model
4. The Morrison Towhead Model
5. The Walkers Bar Model.
6. The Stewarts Bar Model.
7. The Island No 9 Model

The agreement shown in the figures of the model and the prototype is almost complete. Only four figures of the Brooks Point Model are reproduced

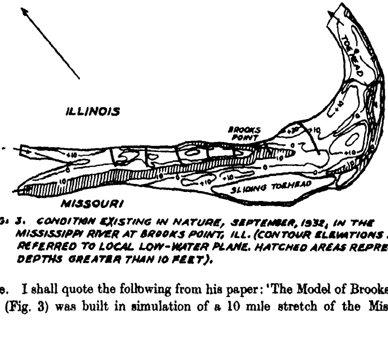

FIG. 3. CONDITION EXISTING IN NATURE, SEPTEMBER, 1932, IN THE MISSISSIPPI RIVER AT BROOKS POINT, ILL. (CONTOUR ELEVATIONS ARE REFERRED TO LOCAL LOW-WATER PLANE. HATCHED AREAS REPRESENT DEPTHS GREATER THAN 10 FEET).

here. I shall quote the following from his paper: 'The Model of Brooks Point, Ill (Fig. 3) was built in simulation of a 10 mile stretch of the Mississippi

River lying between mile 20 and mile 30 above Cairo, Ill. The purpose of the model study was to devise means for improving the depth of the navigation

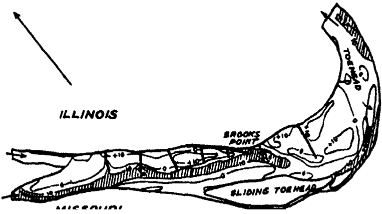

FIG. 4. FLAT BED VERIFICATION RUN, MODEL OF MISSISSIPPI RIVER AT BROOKS POINT, ILL. (CONTOUR ELEVATIONS ARE REFERRED TO LOCAL LOW-WATER PLANE. HATCHED AREAS REPRESENT DEPTHS GREATER THAN 10 FEET.

channel over the crossing at that point during low water stages. Only one general survey of the region was available to the laboratory. This was made in September 1932 and the model was constructed from the data thereof. Fig. 3 shows the condition in the prototype as revealed by the survey. Lacking any other survey data the model was subjected to flat-bed verification test. At the end of 100 hrs operation (Fig. 4) it was found that the model was in close similarity with nature.'

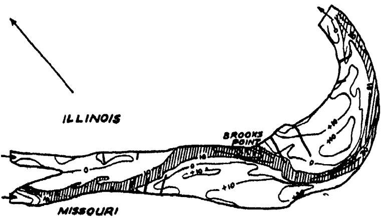

FIG. 5. INDICATED SOLUTION, BY LABORATORY TEST, OF CHANNEL IMPROVEMENTS AT BROOKS POINT, ILL. (CONTOUR ELEVATIONS ARE REFERRED TO LOCAL LOW-WATER PLANE. HATCHED AREA REPRESENT DEPTHS GREATER THAN 10 FEET)

'This model was successful in demonstrating several practical plans for the improvement of the channel at Brooks Point The details of this plan are shown in Fig. 5. In order to preserve the best conditions for navigation, the removal of the dikes was conducted concurrently with the construction of the five new dikes The new dikes were completed in August 1933 but only sections of the old dikes had been removed at this time. A survey

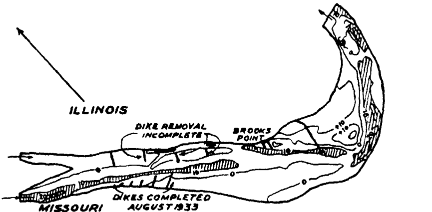

FIG. 6. CONDITIONS EXISTING AT BROOKS POINT, ILL., OCTOBER, 1933 (CONTOUR ELEVATIONS ARE REFERRED TO LOCAL LOW-WATER PLANE. HATCHED AREA REPRESENT DEPTHS GREATER THAN 10 FEET.

of this vicinity, made about two months later (October 1933), is shown in Fig. 6. It can be seen that in this short interval of time the river has shown unmistakable signs of adopting the new channel alignment.'

Having described the various river model experiments in Europe and America it may not be out of place here to mention a few experiments on models of rivers that have been recently carried out in India. The Hardinge Bridge experiments of Mr. Inglis are well known and have been described in detail by him I shall here give a brief description of the experiments recently carried out by the author on a model of the river Chenab below its confluence with the river Jhelum. This was one of the series of experiments on models carried out by the author in connection with the Haveli Project of the Punjab Irrigation Department.

A stretch of the river Chenab about 1 mile upstream of the site where it is joined by the river Jhelum and about 5 miles downstream—the total length of the area included being 6 miles—has been modelled all in pure sand with a depth of sand equivalent to 50 feet in the prototype. The average diameter of the sand used is about the same as that of the prototype. The maximum breadth of the area modelled is about 3 miles. The horizontal scale of the model has been fixed at 1/300 and the vertical distortion has been calculated as 6·5 but it has been found from experiments that a distortion of 6·0 gives a better result. So that the vertical scale has been chosen as 1/50. The rivers

were modelled to the survey of 1915 when a definite number of cross-sections were taken. Accurate discharge observations in these two rivers about 10 miles upstream of the point of confluence are available for the years 1922–37. For fixing the time scale the river was every time modelled to 1915 section and model discharges corresponding to the hydrographs in the rivers were run through the model, the interval of time that corresponded to a month in the prototype was varied from run to run. After each run, which covered the period from 1922–36, the river was surveyed and the cross-sections were compared with those of the prototype for 1936. The time interval that gave the best agreement has been selected as the time scale This in this model was

10 min. = 1 month.

In the model only those months were reproduced in which there is any silt movement or bank formation in the river.

In the prototype there is a gauge site known as Trimmu Gauge Site where discharges and water surface levels have been observed daily since 1922. In the model also the water levels were observed at the corresponding site. The levels for different discharges in the model agreed within an inch or two with the prototype values.

Evidences about the reliability of model experiments for the purpose of anticipating changes in natural rivers are everyday accumulating. Experimenters all over the world are attacking from all points of view one of the most difficult problems of experimental physics, and theories of similitude and hydrodynamics are being constantly called upon to guide this infant science to its goal of success The above comparisons between the characteristics of the model and the prototype show how completely successful has been this new science of River Physics. What Reynolds said about half a century ago is now applicable with greater force. 'This method of experimenting seems to afford a ready means of investigating beforehand the effects of any estuary or harbour work, a means which after what I have seen, I should feel it madness to neglect before entering upon any costly undertaking.'

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